THE PHYSICS OF COMBAT | PROTECTIVE ARMOUR | THE DANGER TO THE BRAIN

ROUGH STUFF

A FIGHT TO THE DEATH MAY not be the aim of modern contact sports but, like the gladiatorial spectacles of Ancient Rome, they still appeal to a deep-rooted desire for confrontation. And, in spite of strict safety regulations, today's gladiators face an ever-present threat of serious injury – even death.

These are the sports where deliberate physical contact is not only allowed but is encouraged as an important part of the play. They include team sports, such as rugby, American football and ice hockey, and also individual sports such as boxing, wrestling and the martial arts.

It is a well proven scientific principle that an object of larger mass will always dislodge a lighter object. So a large sportsman should always overcome a lighter one.

Size and weight

To minimize the advantage given by size, individual contact sports such as boxing are regulated into weight divisions, so that a flyweight (50 kg) is not in the ring with a heavyweight (over 90 kg), which would be both unfair and very dangerous.

Holly Stein/Allsport

***Boxing** is the most lethal of all contact sports: in spite of strict safety regulations, more than 100 professional boxers have died during the last 30 years.*

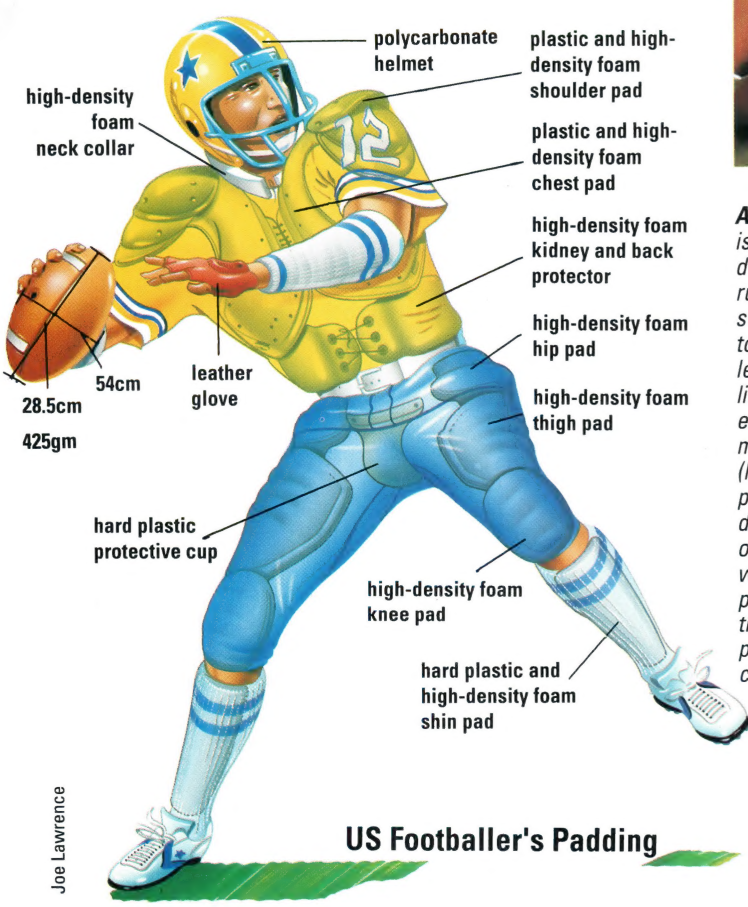
In team sports, size and weight are not always helpful. Ball sports such as rugby also require speed, great agility and stamina. So teams tend to have a blend of large, heavy players and smaller, quicker ones, who fulfil different roles.

The large players either force a way through their opponents' defences, like human battering-rams, or present their own defensive line, like a wall. In rugby, these players are called forwards, and the lighter, faster – and usually more skilful – players are known as the backs.

Rugby allows direct tackles on the opponent's body, but these are regulated. A player may not tackle above the neck, or strike or punch deliberately or use the feet, knees or elbows to win possession of the ball. The perfect tackle requires good timing and technique as much as brute strength; it is not unknown for a fly-half to bring down a rampaging forward nearly twice his weight with a well-timed tackle. But in 'rucks' and in the scrum, weight is a great advantage.

The division between forwards and backs is even more starkly illustrated in American football, which places great emphasis on territorial advantage. The heart of the game is Camp's rule. Devised by Yale University coach, Walter Camp, it states that a team retains possession of the ball only if it can advance it 10 yards in four successive plays, or downs. A match is divided into a series of downs, the ultimate object, as in rugby, is to get the ball over the opposing team's goal line.

Mike Powell/Allsport



Joe Lawrence

US Footballer's Padding

American football *is a much modified descendant of rugby. Although the scoring method – a touchdown (above left) over the goal-line – is similar, extensive body armour is worn (left). This is to prevent injury during tackles and off-ball blocking, where offensive players 'block' their opponents to protect the ball-carrier.*

Substitutions

However, the major difference between American football and other sports is that each team is allowed to make as many substitutions as it likes during a game – they may even change the whole 11 players. So most teams will have an attacking line-up – the offense – and a defending side – the defense – as well as specialists such as goal kickers. Usually the offense is deployed when the team has possession of the ball at a down and the defense is called on when the opposition have the ball.

Because so much of the game involves bone-crunching collisions, American footballers are heavily protected – deaths were not uncommon 100 years ago. Each player must wear regulation safety equipment, which includes a helmet,

shoulder pads, hip pads, thigh pads and knee pads. They may also choose to wear shin pads, a kidney and rib protector, elbow pads, gloves and a gum-shield.

The range of tackles and blocks available to American footballers is wider than in rugby. The whole body may be used to block or obstruct an opponent, so weight can be very important. A typical play will see the ball passed back to the quarterback by the centre of the offense, while each of the linemen tries to bludgeon his way past his opposite number. The quarterback will usually try to throw the ball to a wide receiver who will probably have two or more tacklers running at him to bring him down as soon as possible.

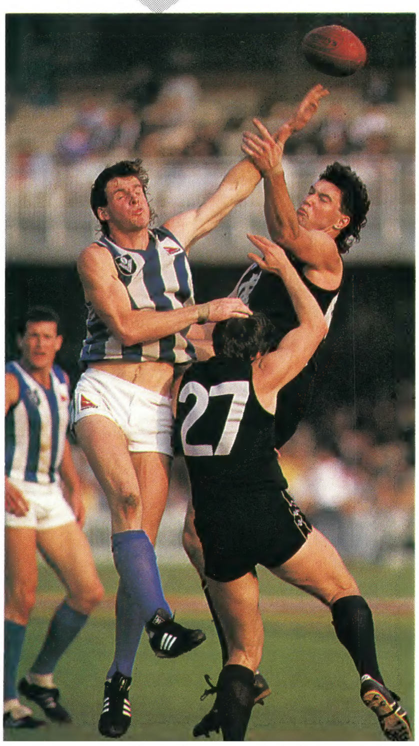
So it is not surprising that there are some serious injuries. The most common are strains of the knees and ankles, severe bruising and bone fractures. But, as in rugby, it is not unheard of for players to be paralysed by broken spines, or, very rarely, killed.

The most lethal of all contact sports, however, is undoubtedly boxing. The aim of boxing is to land more and better punches than your opponent. However, in doing so,

Russell Cheyne/Allsport

Colorsport

***Rugby League** is essentially a handling game. Although a drop-goal is kicked over the bar it is worth less than a 'try'. Superficial injuries (above) are a common feature.*

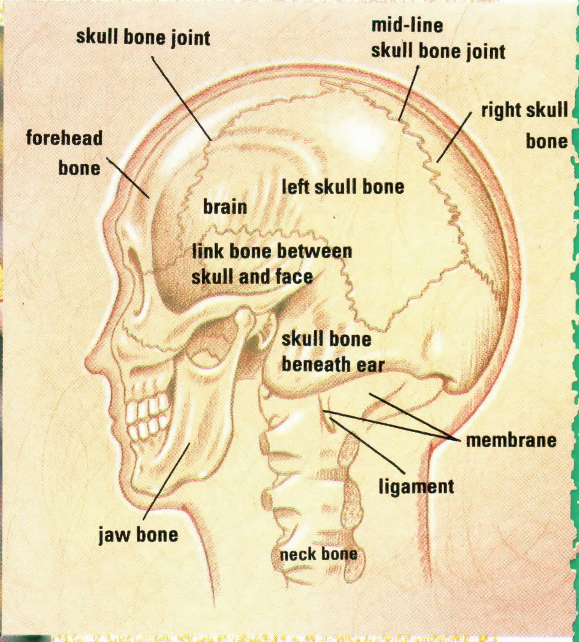


Colorsport

***Australian Rules Football** is a tough game unique to Australia, fought between teams of 18 players over pitches 150 to 200 metres by 120 to 170 metres.*

THE HIDDEN DANGERS OF HEADING A FOOTBALL

David Cannon/Allsport



Joe Lawrence

One of the most spectacular and unique techniques in football is the use of the head to play the ball. Typically, the 450 gm plastic-covered ball contacts a player's head at 70 km/h, so correct method is essential, not only to maximize control but to help prevent injury. Players are taught to fix their eyes on the ball, watch it on to the forehead and cushion its force by bracing their neck muscles. In the hurly-burly of a game, however, an attacker often has to contend with one or more defenders (left), intent on forcing him off line and balance.

Incorrect technique can result in concussion and, rarely, in more serious injury. Whereas the joint between the two halves of the skull – the mid-line skull bone joint (above) – normally knits into a strong spherical shape, it can join imperfectly, leaving a small, and relatively weaker, ridge. In such cases, incorrectly heading a football can move the skull bones fractionally, causing headaches or double vision.

A further problem is the accumulative wear of heading on the muscles of the neck. If over-strained, the small ligaments and membranes in the neck can tear and this may lead to an increasing likelihood of painful arthritis of the neck some 15 or so years later.

fighters can run grave risks – the more so because a fighter's injuries may only be apparent after the fight. In addition, deciding that a fighter is unfit to continue boxing is left to the discretion of the referee who, being human, may make a mistake and not stop the fight before serious injury has been done to a boxer.

The art of boxing is to defend yourself against the worst blows, while trying to get in punches of your own. But even the best boxers take enormous punishment, because heavy blows are landing on sensitive areas of their bodies throughout the bout. Muhammad Ali, for instance, has calculated that he took 1.5 million blows in his 25 years in the ring.

Vandystadt/Allsport

***Sumo wrestling** is the heavily ritualized Japanese national sport. Great reliance is placed on weight, with some champions scaling over 130 kg. The aim is to force an opponent to the ground or out of the 3.6-metre circle.*

The worst types of injury, however, are to the head. Brain injuries caused by punches can be of three kinds:

- straightforward concussion, which results from a shock wave through the brain and renders the victim unconscious.
- a torn blood vessel, which quickly leads to unconsciousness
- slow bleeding in the brain with a delayed onset of unconsciousness.

Other major problems that boxers can suffer are having the retina of the eye detached by frequent blows to the head, and damage to the soft tissues of the brain.

Bare-knuckle fighting

This last injury is thought to be one of the main causes of boxers becoming 'punch drunk' – the condition that is shown by the dulled reflexes and slurred speech of many ex-boxers. It will usually involve memory lapses, blackouts and even premature senility, yet may only show up years after a boxer has retired from the ring.

The problem has led one boxing magazine to argue for a return to bare-knuckle fighting. This was the norm over a hundred years ago, before the introduction of rules laid down in England by the Marquess of Queensberry, which among other things, required boxers to wear gloves. Today's argument is that as gloves protect the hands, much heavier punches can be landed. Therefore, if boxers fought without gloves, they would not be able to cause so much brain damage, although the number of facial cuts would increase. Cuts, it is argued, will heal, whereas brain damage is irreversible.

Sipa/Colorsport

***Thai boxing** is a fast-moving martial art that grew out of the ancient Siamese military training syllabus. In its modern form, contestants are matched as much by experience as weight. Boxers wear 220 gm gloves and can punch the body or the head. Kicks with the shin and knee are allowed to the legs and body but not to the head. Bouts are over three 2-minute rounds or five 3-minute rounds.*

PROFILE — BOXING DIVISIONS

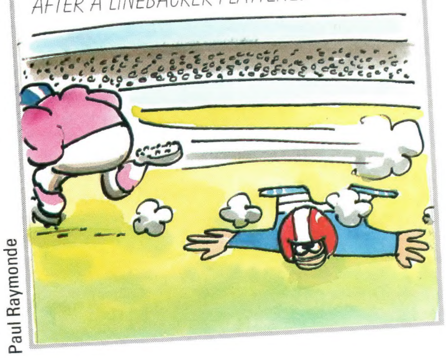
Weight categories	Amateur (IABA*)	Professional (WBC*)
Straw–	—	47.6 kg
Light fly–	48 kg	49 kg
Fly–	51 kg	51 kg
Bantam–	54 kg	53.5 kg
Super bantam–	—	55 kg
Feather–	57 kg	57 kg
Junior light–	—	59 kg
Light–	60 kg	61 kg
Light (junior) welter–	63.5 kg	63.5 kg
Welter–	67 kg	66.5 kg
Light middle–	71 kg	70 kg
Middle–	75 kg	72.5 kg
Light heavy–	81 kg	79 kg
Cruiser–	—	88.45 kg
Heavy–	91 kg	88.45+ kg
Super-heavy–	91+ kg	

*IABA: International Amateur Boxing Association
*WBC: World Boxing Council

Just amazing!

SHORT CAREER

IN 1970 PAT PALINKAS BECAME THE FIRST LADY AMERICAN FOOTBALLER WHEN SHE HELD THE BALL FOR HER PLACE-KICKER HUSBAND. SHE RETIRED IMMEDIATLEY- AFTER A LINEBACKER FLATTENED HER!



Paul Raymonde

SUPER CYCLING

Vandystadt/Allsport

Mike Powell/Allsport

The Tour de France *is the longest-lasting sporting event on land in the world, taking 21 days to complete. The 4,000 km course over both flat and mountainous terrain demands speed and stamina. In tandem sprinting (right), riders race over a distance of about 1500 metres.*

COMPETITIVE CYCLING IS ONE of the fastest-growing sports of the 1990s. To succeed at the highest level, the cyclist must be in peak condition. He or she also needs a precision-crafted machine that may cost almost as much as a small car.

A specialized road-racing bike may look like a standard sports bike, but there are several differences. First, there is the frame. It has to be strong and light, but also flexible enough to cope with the twists and turns of racing. The most popular material is chrome-molybdenum alloy steel, between 0.7 and 1.0 mm thick. Weight is saved by a process called butting, which means the tubes are thinned out internally where the least strength is needed.

The really expensive machines have frames made of lightweight aluminium or titanium-alloy. The best frames are hand-made and weigh no more than about 2.5 kg. Expensive titanium-alloys are also used for the accessories. The handlebars are usually made of duralumin alloy, about 1mm thick. This is an aluminium-based metal that is as strong and as hard as steel.

Gamma/Frank Spooner Pictures

Some track bikes *are fitted with solid carbon-disc wheels to reduce wind resistance. The tyres are sometimes filled with helium to lessen weight. Track machines have no brakes or gears and the back wheel cannot freewheel. Riders slow down by exerting backward pressure on the pedals or placing a gloved hand over the front wheel.*

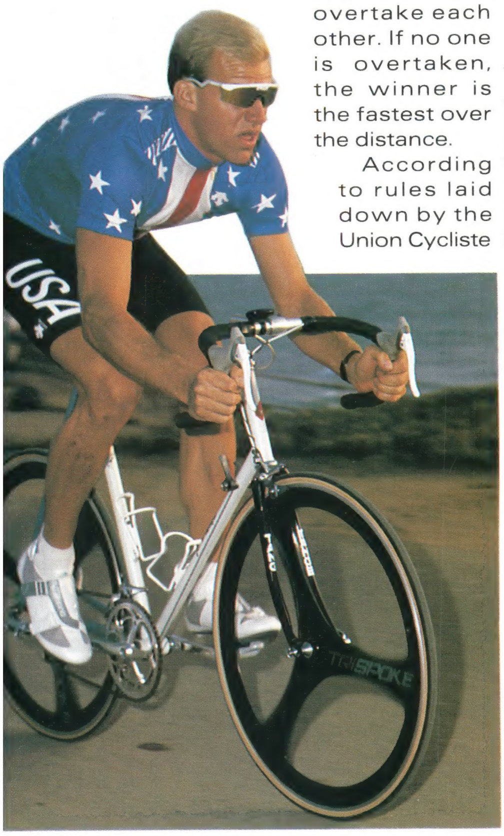
Tubulars

A racing bike's tyres, known as tubulars, have a carcass of fine cotton or silk sown around a very light inner tube. The outer surface is covered with a light tread, and the whole tyre is stuck on to the wheel rims with cement or special rim tape. All tyres perform best after they have been 'matured' for a year or more in a cool, dark room, lightly inflated on wheel rims. This hardens the tread.

Track bikes, used on single-lap tracks, have smaller and stronger frames to cope with the sideway stresses of speed cycling. They weigh between 6 and 8 kg, whereas a road-racer is typically 8.5 to 10.5 kg. Even lighter is the Lotus superbike, on which Chris Boardman won a gold medal for Britain at the 1992 Olympics. It has a one-piece carbon fibre frame.

Track events take place on a velodrome, which should have banked corners and be no more than 500 metres long. Track-racing consists of time-trials, sprints and team or individual pursuits. In pursuit racing, riders or teams start at opposite sides of the track, and the object is to overtake each other. If no one is overtaken, the winner is the fastest over the distance.

According to rules laid down by the Union Cycliste Internationale (UCI), cycling's world governing body, all road-racing riders must wear cycling shoes, white ankle socks, short black racing shorts, a racing jersey and a crash hat or helmet. Crash-hats are made out of padded leather bars and are held in position by a chin strap. Plastic helmets that cover the whole head are lighter, better ventilated and give better protection against the sun's rays. Road-racing jerseys are made of pure wool or a mixture of wool and acrylic. They usually have pockets where riders keep their race food. To lower wind resistance, track riders taking part in time trials and circuit races wear silk jerseys or aerodynamic one-piece suits.

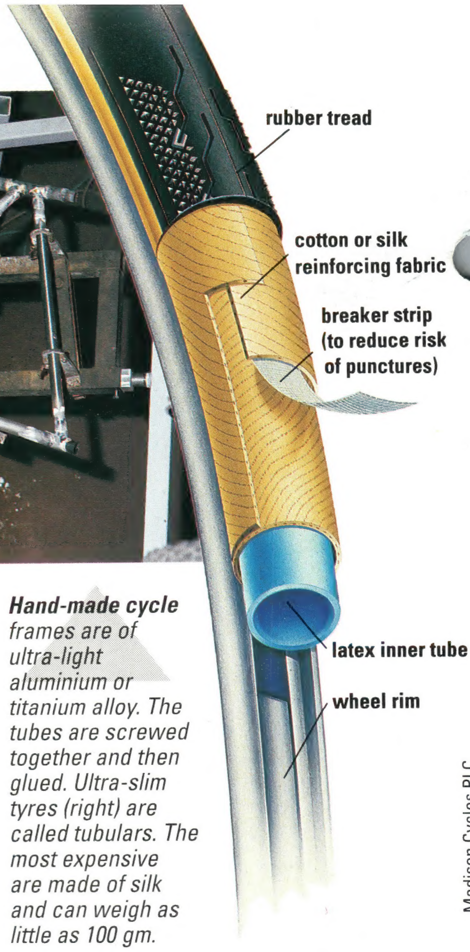


Photosport International

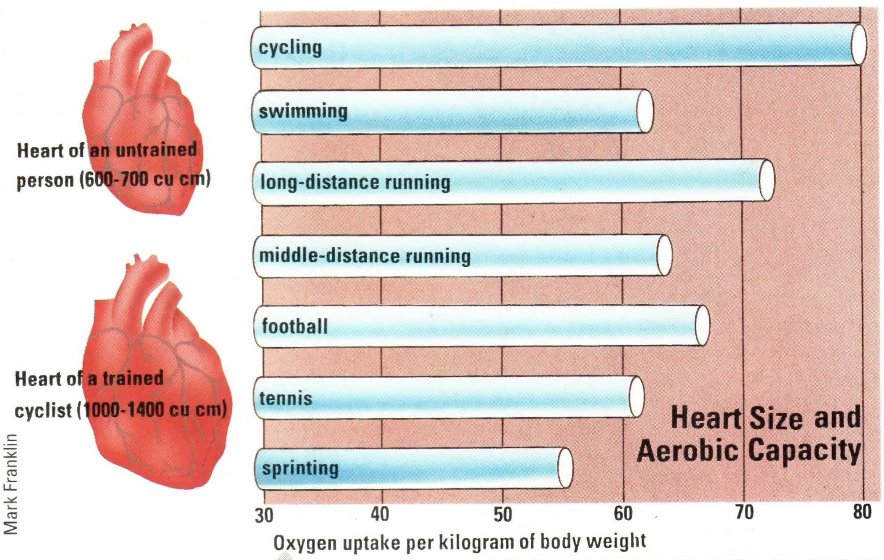
Tri-spoke wheels are up to four per cent faster than carbon-disc or spoked wheels because they are less affected by side-wind resistance. They are made of a substance called Carbon Kevlar.

Photosport International

Hand-made cycle frames are of ultra-light aluminium or titanium alloy. The tubes are screwed together and then glued. Ultra-slim tyres (right) are called tubulars. The most expensive are made of silk and can weigh as little as 100 gm.



Madison Cycles PLC



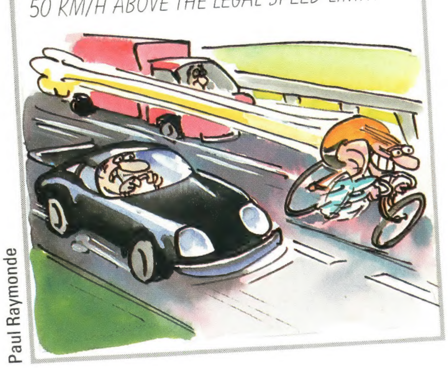
Mark Franklin

Cycling is the best sport for achieving aerobic fitness. A racing cyclist's heart muscle increases in size during training – and may grow to twice that of an unfit person's heart.

Just amazing!

PEDAL POWER

THE FASTEST RECORDED SPEED BY A CYCLIST ON AN OPEN ROAD WAS 158 KM/H BY DAVID LE FRYS ON A STRETCH OF THE M42 MOTORWAY, UK, IN 1985 – ALMOST 50 KM/H ABOVE THE LEGAL SPEED LIMIT!



Paul Raymonde

Feet first

The racing shoe is probably the most important item of equipment for the competitive cyclist. The uppers are made of soft box-calf leather and have holes to allow the feet to breathe. Most shoes have a leather sole with a steel, aluminium or plastic plate insert. This prevents the shoe from sliding around on the pedal.

THE BIG WHEEL

Italian cyclist Francesco Moser pioneered the use of carbon-disc wheels when he broke the world one-hour cycling record in 1984. These have now become the standard in record attempts and track-racing. But Moser has now gone one step ahead of the rest – he is using a bike with a rear wheel one metre in diameter. This allows him to use a more efficient gear ratio than normal. It also increases the gyroscopic effect (momentum) of the wheel, providing greater stability and a much smoother running bike.

Even with a slightly larger front wheel than usual, the combined weight is still less than the wheels used in his 1984 record.

ON TARGET

Allsport

TARGET SHOOTING IS ONE of the oldest and most popular participatory sports in the world. From archery to air-rifle shooting, the aim is the same – to direct a projectile at a target with maximum accuracy and consistency.

Good marksmanship relies on simple basic principles – accurate aiming from a steady base, calmness and concentration. Successful archery depends on the archer's body and stance controlling the angle and direction of fire. The arrow is delivered by releasing the drawn string of a bow. Although it has been estimated that 90 per cent of archery is due to the archer's skill and only 10 per cent is due to the equipment, there are strict guidelines for the archer's tools.

Strong bows

The bow can be simple or complicated. It must have the same basic design of a grip, two flexible limbs and a single bowstring. The bow can be a curved longbow, a recurve bow that has a double curve at each end or a compound bow, using cams and pulleys to give greater force (see NEW TECHNOLOGY, page 43).

The string is usually made of Dacron or Kevlar. Dacron fibre, with up to 12 strands twisted together is long-lasting but tends to stretch slightly. Kevlar is the strong yet lightweight material used in armoured cars and bullet-proof vests.

Kevlar strings do not stretch, but they have a limited life of between 1,000 and 2,000 arrows – a typical day's shooting will be around 150 arrows. Each string needs to be 'shot in' for about 100 arrows, so a Kevlar string will not last much more than a month.

Arrows used to be wooden, but now most are made of tough aluminium alloy, which means they can be straightened if they become bent. The length depends on the size and experience of the archer. Top

Russell Cheyne/Allsport

Archery's basic principles have hardly changed over the centuries, but the bows and arrows are now made of plastics and Kevlar; targets may soon be made of foam instead of straw.

Just amazing!

LONG-RUNNING ARCHERS

THE OLDEST ARCHERY CONTEST IN THE WORLD IS THE PA-PINGO SHOOT BY THE KILWINNING ARCHERS IN SCOTLAND, WHICH HAS BEEN RUNNING SINCE 1488.

Paul Raymonde

Allsport

Wheelchair archers thrive in a sport in which they can compete on equal terms against able-bodied sportsmen and sportswomen.

archers use carbon arrows, which do not bend. The flights – or 'fletchings' - are usually made of plastic rather than natural feathers.

Loosing arrows

As well as the basic equipment, many archers use stabilizers fitted in front of the bow. They make the bow heavier and lower its centre of gravity, which helps reduce the movement in the hand when the string is 'loosed', or released.

A simple sight is permitted on the bow as long as it has no lens or prism. It may be no more than a ring with a pin in the centre. The archer aligns it with a point on the target, so that he can shoot with the bow in the same position every time. The essence of good archery is to find the target, and then to keep hitting it by maintaining a consistent draw weight and trajectory time after time.

Shooting

The same principles of accuracy and consistency apply to the shooting of firearms, except that the propellant force of the bullet or pellet will automatically be the same for every shot.

The only occasion lenses or telescopic sights are allowed in shooting is in running game target, an Olympic event that involves shooting at a moving target with ten concentric scoring rings. The target is carried across a 10-metre-wide opening on a trolley designed to give the impression of a running animal. The competitor must hold the rifle in a standing position. He is allowed 30 shots with the target moving slowly and 30 shots with it moving quickly. This means that as well as calculating the distance, trajectory and velocity of the bullet, he must also allow for sideways movement.

S G & N Products

***Smallbore rifle shooting** (requires an accurate aim to hit the target (actual size, left). Each rifle butt is tailored to suit the marksman; the glove reduces hand tremors.*

Clay-pigeon shooting

Another Olympic event in which the targets are not fixed is clay-pigeon shooting, derived from live pigeon shooting, which was outlawed in Britain in the 19th Century.

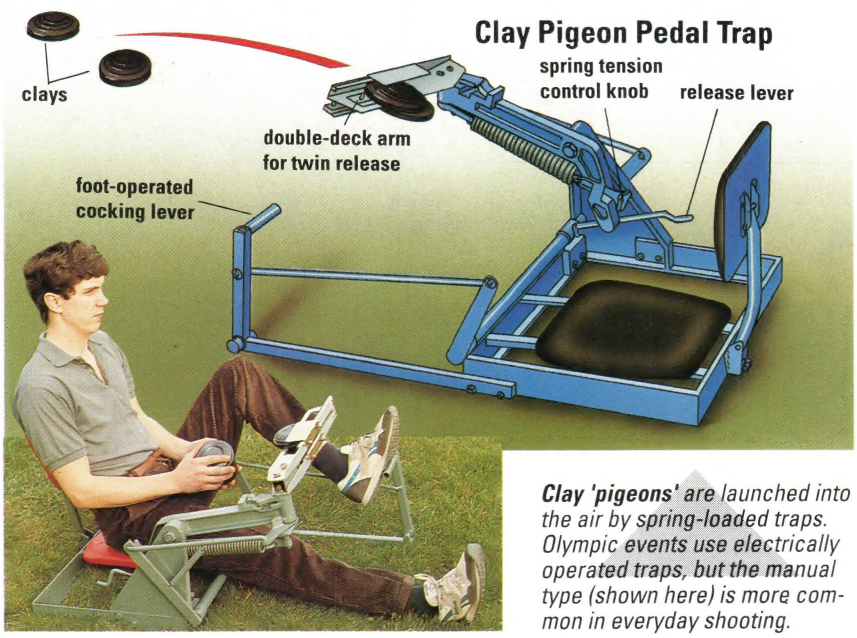
Measuring 110 mm in diameter, clays are launched by mechanical traps in wide arcs above the competitors, who use double-barrelled shotguns loaded with lead-shot cartridges. In this sport, the careful aim of the archer or fixed target shooter is not as important as a trained eye and fast reactions.

Gray Mortimore/Allsport

Smallbore rifle shooting involves three positions – standing, kneeling and prone. Steady nerves are needed to stop the rush of adrenalin that can ruin a marksman's aim in a big competition, so mental relaxation is vital. Keeping as still as possible is essential and the top marksmen have enormous mental and physical control. Concentration must be total to control muscles and maintain a good hold, thus aiming accurately.

Breathing exercises

Many marksmen use special breathing exercises to help them remain virtually motionless while they aim and shoot. Their breathing becomes shallower as the target is lined up, and may stop for up to 8 seconds as they pull the trigger – anything longer would starve the brain of oxygen and cause loss of concentration.



W J Bowman/Mark Franklin

***Clay 'pigeons'** are launched into the air by spring-loaded traps. Olympic events use electrically operated traps, but the manual type (shown here) is more common in everyday shooting.*

THE MASTER EYE

Most people have one dominant eye that is unconsciously used more when looking at an object. It is this eye that is preferred when looking through a camera or lining up a target. Archers or shooters use this simple test to find out which is their master eye. Hold both index fingers in front of you, 10 cm apart. Keep both eyes open and line up the fingers. Now close the left eye and see if the fingers are still aligned – if they are, then the right eye is dominant. If not, close the right eye and keep the left eye open – if your fingers line up, it means the left eye is dominant. If the fingers don't line up with either eye, but only with both eyes open, then neither eye is the master eye and you may use whichever one you wish.

CONDUCTORS

CORROSION

METAL ORES

METALS

METALS ARE INCREDIBLY useful materials. People have been using metals for 8,000 years and yet, even in this age of plastics, they remain an important part of our lives. Metals are resistant to heat, and they conduct electricity – a feat no plastic can achieve.

Claus C Meyer/Colorific!

***In the hostile environment** of a steel works, iron is combined with carbon to make the harder alloy steel.*

Metals generally have a shiny appearance, or metallic lustre, and they can usually be fashioned into thin sheets by hammering – a property known as malleability. Some metals are described as being ductile, which means that they can be drawn out into thin wires.

As well as conducting electricity, metals are good conductors of heat. They all behave chemically in a similar way, too. When metals react with oxygen they form substances known as bases, or alkalis. A base is a chemical that reacts with an acid to form a salt, which is a combination of a metal and one or more non-metals; examples include common salt, or sodium chloride, lead sulphate and potassium nitrate.

Semi-metals

Of the 92 naturally occurring elements, 69 are classed as metals, but there are also five semi-metals – elements that sometimes behave like metals and sometimes like non-metals. These are boron, germanium, arsenic, selenium and tellurium.

The properties of metals differ from one to another and this makes them useful for different purposes. For example, the best conductors of heat and electricity are silver and copper, but, as silver is less widely available, it is copper that is generally used in electricity cables and heating systems. Iron is very common and also very easy to work. This and the fact that it can be turned into the much harder form known as steel, makes it the world's most commonly used metal. Most metals are solid at normal temperatures, but mercury is a liquid. It expands noticeably when

***Metals have many uses.** These huge rolls of sheet aluminium will be made into parts for cars, ships and planes - and into foil to wrap the Christmas turkey.*

Tony Stone Photo Library

Tony Stone Photo Library

***Gold bars** are made by heating gold in a furnace until it melts at 1064°C. The molten metal is poured into moulds where it cools and solidifies.*

heated and is therefore mainly used in thermometers.

Some metals react with other chemicals very easily. Sodium and potassium, for example, react by fizzing violently on contact with water and are never found in the pure state in nature. Other metals react more slowly; iron, for example, forms iron oxide (rust) when exposed to air and water, and copper eventually becomes covered in a green film – a type of copper carbonate.

Gold and silver

Among the metals that are least susceptible to corrosion in air are lead and aluminium. Lead is a rather soft, dense metal and, in its pure form, is limited to such things as roofing and car battery plates. Aluminium, on the other hand, is a much harder metal that is very easy to work. It therefore has a very wide range of uses including car bodies, aircraft frames, long-distance power transmission lines, window frames, saucepans and kitchen foil. The least reactive metals are silver and gold, which, being rare, are used to make jewellery.

Mineral ores

Some metals occur in the pure, or native, state in nature. Most gold, for example, is obtained in this form, and in a few places native silver and copper can be found. All other metals are obtained in the form of mineral ores. These have to be dug up and then treated to obtain the pure metals.

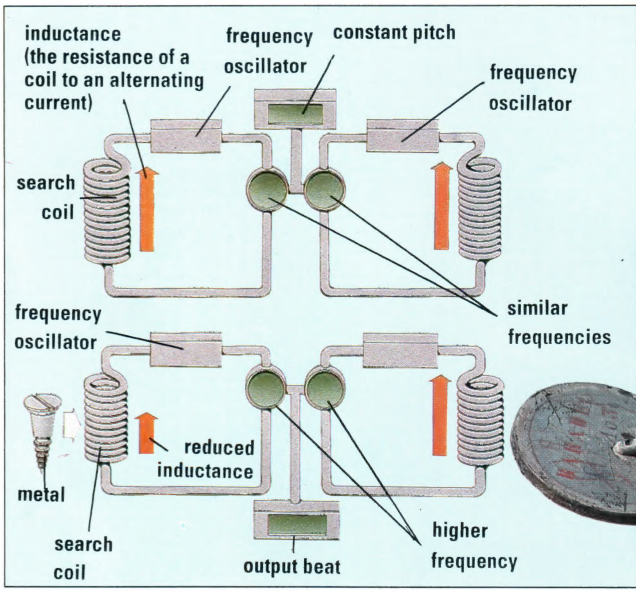
A metal ore is generally extracted from the ground by mining, either on the surface or deep underground. The details of the process in which a metal is then extracted from the material that is mined varies from metal to metal. Usually, the ore is first separated from the gangue – unwanted earth and rock. Some metal ores, such as those of iron, lead, tin and copper are then smelted (heated to a high temperature in a furnace with other chemicals) to release the metal. Aluminium, on the other hand, is extracted by a chemical process to produce a chemical known as alumina, which is then electolysed – that is, electricity is passed through it – to produce pure aluminium.

Some metals are more dense than others, which means that the matter they contain is concentrated into a smaller space. For example, lead is very dense, which is why a small piece is so much heavier than a similarly sized piece of aluminium.

MIXING METALS

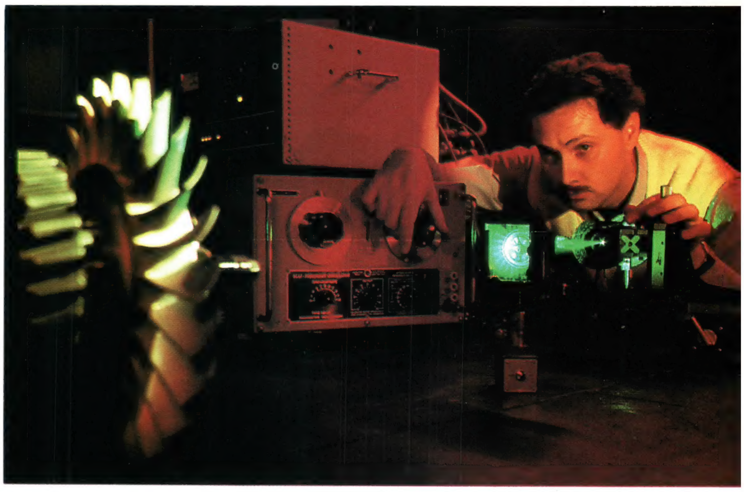
An alloy is formed when metals are melted together. One familiar alloy is stainless steel, which is steel mixed with chromium and nickel. The chromium at the surface reacts with oxygen in the air to form a thin layer that prevents corrosion. Adding manganese to steel makes it tougher, and molybdenum and tungsten help steel tools stay sharp.

Copper and zinc form brass, which is more resistant to corrosion. Bronze is an alloy of copper and tin; it melts at a lower temperature and is easier to cast. Pewter is an alloy of lead with antimony and copper, and dentist's amalgam for fillings is composed of mercury and copper. Sterling silver contains 7.5 per cent copper while 18-carat gold contains 25 per cent silver and copper.



Coty/Jerrican

***A metal detector** works by comparing the frequencies in two circuits (left). When one coil comes near metal, the listener hears a series of pulses*



Philippe Plailly/Science Photo Library

***Holograms are** used to test metal helicopter rotors. Once the hologram has been made the real rotor can be subjected to severe vibrations, then it can be compared with the hologram in laser light so that minute distortions can be detected.*

Just amazing!

STEEL BAND

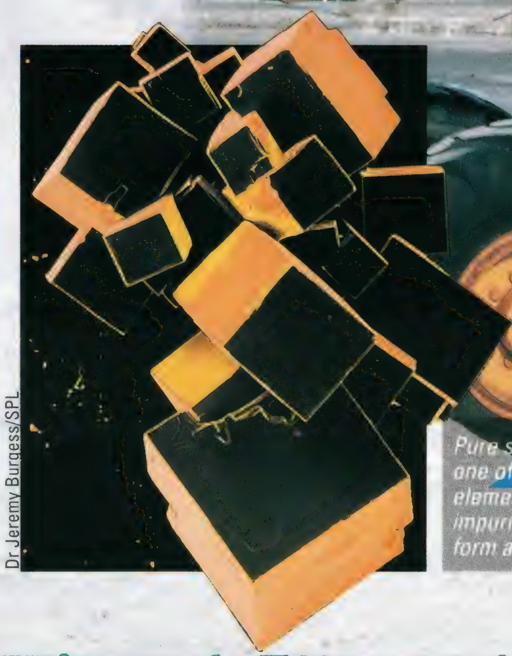
700 MILLION TONNES OF STEEL IS PRODUCED WORLDWIDE EACH YEAR -- ENOUGH TO MAKE A 1-MM-THICK WIRE THAT WOULD WRAP ROUND THE WORLD OVER 28 MILLION TIMES.

Paul Raymonde

MATERIAL MATTERS

- ATOMIC NUMBERS
- THE BIG BANG
- RADIO ISOTOPES

Tony Stone Photo Library, London



Dr Jeremy Burgess/SPL

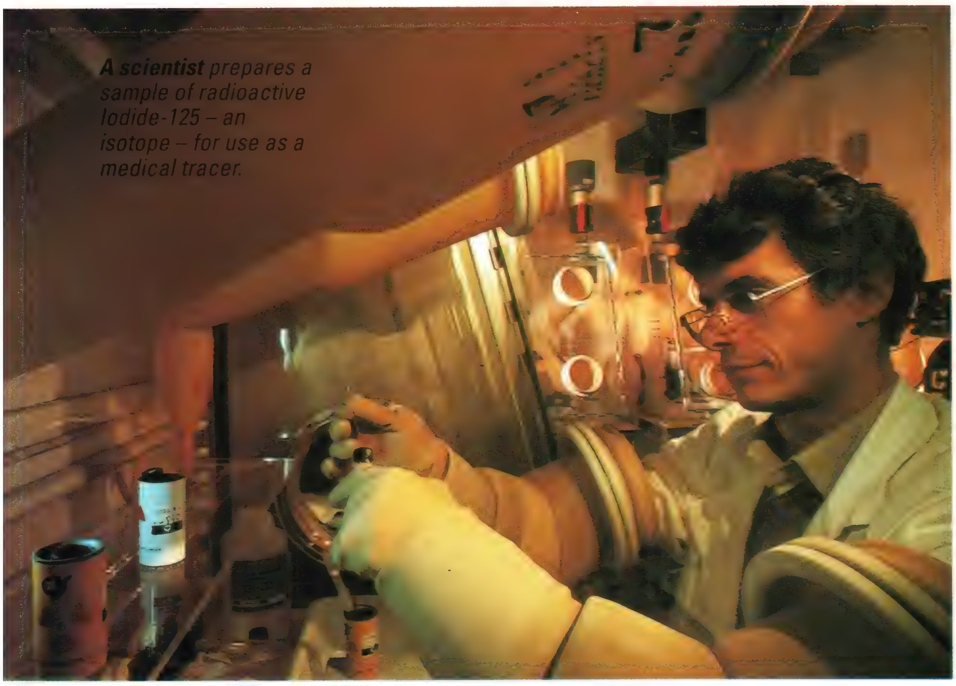
Pure salt – sodium chloride – is one of the most common elements. In the absence of impurities, the crystals (inset left) form an exact cube

EVERYTHING AROUND US, every material or substance that we can see or feel, is made of what scientists call matter. And all matter is made up of tiny particles called atoms. There are a number of different kinds of atoms. However, when all the atoms in a substance are exactly the same, the substance is known as an element.

Scientists know of over 100 different elements. Of these 92 occur naturally in the world about us. Examples include hydrogen, helium, oxygen, carbon, iron, silver and lead. Each element is known by a name given to it when it was first discovered. Each element is also distinguished by a number, called its *atomic number* – defined by the number of protons in the atom. Hydrogen is thus 1, helium 2 and so on.

Artificial elements

All the known elements can be arranged in a table, known as the Periodic Table (see Dataquest, Issue 39), in which the horizontal rows show the elements in the order of increasing atomic number. The vertical



A scientist prepares a sample of radioactive Iodide-125 – an isotope – for use as a medical tracer.

Philippe Plailly/Science Photo Library

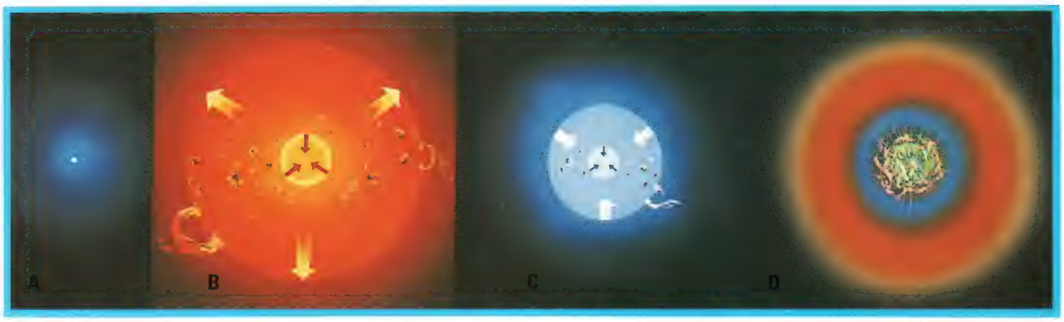
columns, known as periods, contain elements that have similar chemical characteristics.

Elements with atomic numbers of over 92 do not occur in nature, but they can be made artificially. The elements neptunium (atomic number 93) and plutonium (94), for example, are formed when uranium is bombarded with slow-moving neutrons in a nuclear reactor. Americium (95) can be made by bombarding plutonium with neutrons, and curium (96) is made by bombarding plutonium with the nuclei of helium atoms. This has to be done at very high speed and an accelerator is used to get the helium nuclei moving fast enough.

Super-heavy elements

Scientists have made elements with atomic numbers of up to 108 and in 1987 a group of Russian scientists claimed to have made one with an atomic weight of 110. These elements exist for only a few milliseconds, before they rapidly decay into elements with lower atomic numbers. However, some scientists suggest that if so-called super-heavy elements, with atomic numbers of over 114, could be made, they might perhaps be more stable.

Of course, all of the elements that occur naturally were also created. But they were created by the events that formed the universe. The simplest and smallest atoms were created first, during the huge explosion known as the Big Bang. One tenth of a second after the Big Bang took place the first protons had been formed. Four minutes later these protons had interacted to form the lightest elements, hydrogen, helium, and lithium. The hydrogen and helium then began to form stars, inside which heavier elements began to form. Helium nuclei fused to form beryllium, and beryllium nuclei fused with helium nuclei to form carbon – the element that is a vital part of every living thing on Earth. Next carbon and helium nuclei fused to form oxygen, and so on until all the elements that we know were formed. Some of the early stars blew themselves apart in explosions known as supernovae, scattering the newly-formed elements far and wide. Over many millions of years the elements were spread throughout the universe.



Supernovae, *the violent explosions of stars, are responsible for distributing all the natural elements. A blue star (A), powered by hydrogen fusion, expands to form a red giant (B), which collapses (C), then rebounds (D) – blowing the star apart.*

Sally Bensusen/Science Photo Library

Mass numbers

Different forms of the same element – that is, atoms with the same number of protons, but different numbers of neutrons – are known as isotopes. To distinguish isotopes of the same element from each other they are normally known by their mass numbers, that is the total number of protons and neutrons in each atom. Thus normal hydrogen is hydrogen-1, deuterium is hydrogen-2 and tritium is hydrogen-3. In practice most elements exist as two or more isotopes, and so their atomic weights are seldom nice round figures. Iron, for example, has four main isotopes, iron-54, iron-56, iron-57 and iron-58. The normal atomic weight of iron is 55.84, which

ROCK WEAR

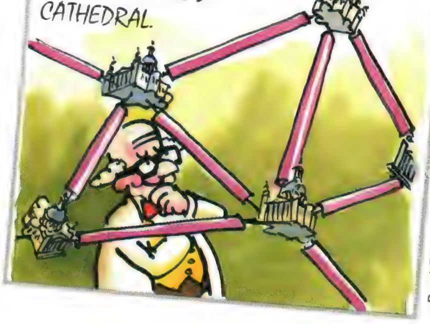
Asbestos is the name given to the fibrous forms of several kinds of rock. Strictly, asbestos is the fibrous form of actinolite. Most commercial asbestos, however, comes from another mineral – chrysolite. Its fibres are short but fine and strong; 1 kg of chrysolite can produce 88,700 metres of asbestos thread.

Being made of rock, asbestos does not burn, and its melting point is very high. And because it is fibrous, it is easy to weave into fabrics and compress into flat panels in order to create fire-resistant materials. Unfortunately, if people breathe in the tiny fibres they can develop a disease known as asbestosis. The sharp fibres irritate and damage the delicate lining of the lung, and may also pierce the lung and damage the outer lining. Sufferers often develop lung cancer.

Just amazing!

A NUCLEAR MARBLE

THE ELECTRON/NEUTRON-CONTAINING NUCLEUS OF AN ATOM IS THE SMALLEST PART. IF IT WAS AS BIG AS A MARBLE, THE WHOLE ATOM WOULD BE THE SIZE OF ST.PAUL'S CATHEDRAL.



Paul Raymonde

reflects the relative abundance of these isotopes.

In most cases isotopes are unimportant to us. A few, however, are useful. Deuterium, for example, is used in the form of deuterium oxide, or heavy water. Heavy water (see PLANET EARTH page 69) has the property of being able to slow down moving neutrons more easily than normal water. It is therefore used in some nuclear generating plants as a combined reactor coolant and moderator (neutron slower).

Among the most useful isotopes are those that are radioactive. These are unstable isotopes that naturally break down, or decay, into other elements. They do this by giving out radiation in the form of sub-atomic particles – either an alpha particle (two protons and two neutrons) or a beta particle (an electron moving at high speed). Sometimes gamma rays are given out as well. Alpha particles, beta particles and gamma rays can be detected using special equipment, such as a Geiger counter. So radioactive isotopes, or radioisotopes, make excellent tracer materials. If a radioisotope is fed into a mechanical, chemical or biological system, its path through the system is easy to follow.

Radioisotopes are now widely used in medicine, in industry and in scientific research. For example, iodine-131 can be injected into a patient's body to test how well the thyroid gland is working. Iodine normally accumulates in the thyroid gland and by detecting how much radioactive iodine accumulates, doctors can find out if the gland is underactive, overactive or working normally. Other isotopes used in medicine include strontium-85, technetium-99 and indium-111.

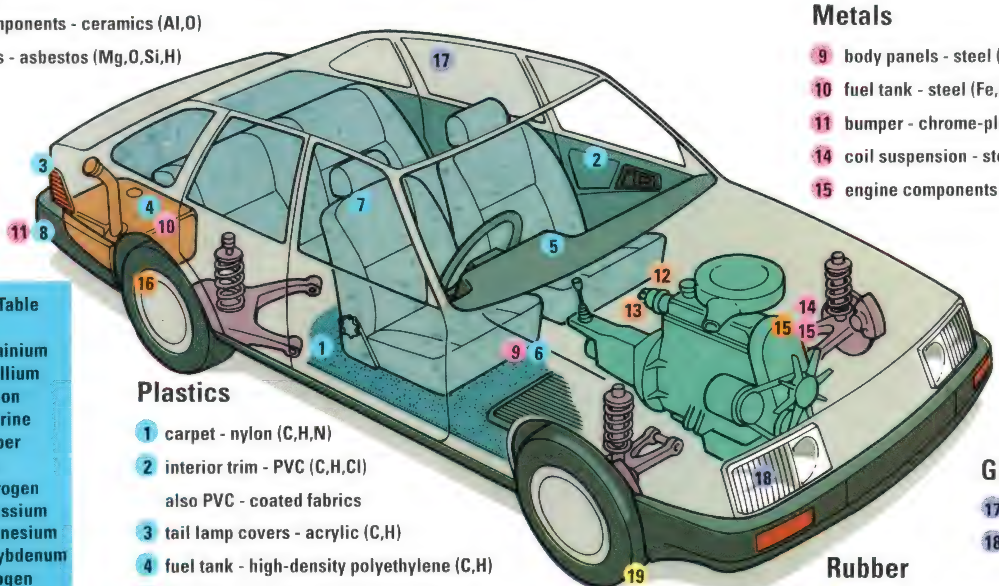
***Petroleum** is a naturally occurring mixture of hydrocarbons, often found with traces of sulphur and vanadium. Although widespread in the Earth's crust, oil companies have increasingly had to search and drill – from rigs such as the Claymore-A in the North Sea – beneath the sea.*

Richard Folwell/Science Photo Library

***Radiation** from the nuclear accident at Chernobyl, Ukraine in 1986 sent farmers out with Geiger counters to check their crops.*

Gamma/Frank Spooner Pictures

***The modern car** consists of a vast 'stew' of chemical elements. The most commonly occurring is carbon – found in just over a fifth of the materials.*



Paul Williams

Ceramics

15 engine components - ceramics (Al,O)
16 disc brakes - asbestos (Mg,O,Si,H)

Metals

9 body panels - steel (Fe,C)
10 fuel tank - steel (Fe,C)
11 bumper - chrome-plated steel (Fe,Cu)
14 coil suspension - steel vanadium alloy (Fe,C,V)
15 engine components - aluminium (Al)
beryllium (Be)
lead (Pb)
molybdenum (Mo)
nickel(Ni)
steel (Fe,C,W)
tellurium (Te)
zinc (Zi)

Glass

17 windows - glass (Si,O)
18 headlamps - glass (Si,O)

Rubber

19 tyres - vulcanized rubber (C,H,S)

Plastics

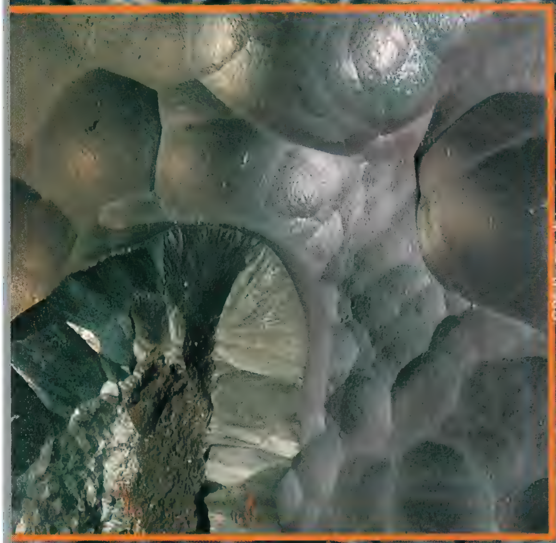
1 carpet - nylon (C,H,N)
2 interior trim - PVC (C,H,Cl)
also PVC - coated fabrics
3 tail lamp covers - acrylic (C,H)
4 fuel tank - high-density polyethylene (C,H)
5 fascia panel - ABS polypropylene (C,H)
6 body panels - glass reinforced plastic (C,H,Si,O)
7 seats - polyurethane (C,H) + other plastics
8 bumper - ABS (C,H,N) polycarbonate (C,H,O)
polypropylene (C,H)

Minerals

12 distributor head - mica (Mg,Al,Si,K,O,H)
13 distributor - talc (Mg,Si,O,H)

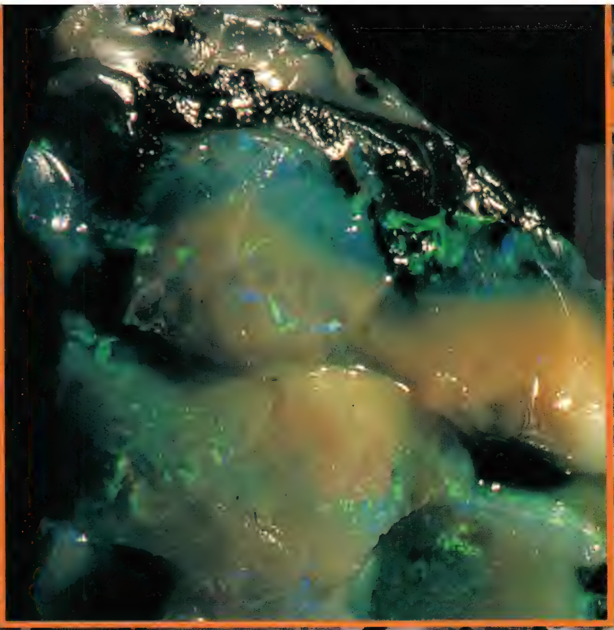
Elements Table

Al	aluminium
Be	beryllium
C	carbon
Cl	chlorine
Cu	copper
Fe	iron
H	hydrogen
K	potassium
Mg	magnesium
Mo	molybdenum
N	nitrogen
Ni	nickel
O	oxygen
Pb	lead
Si	sodium
S	sulphur
Te	tellurium
V	vanadium
W	tungsten
Zi	zinc



GSF Picture Library

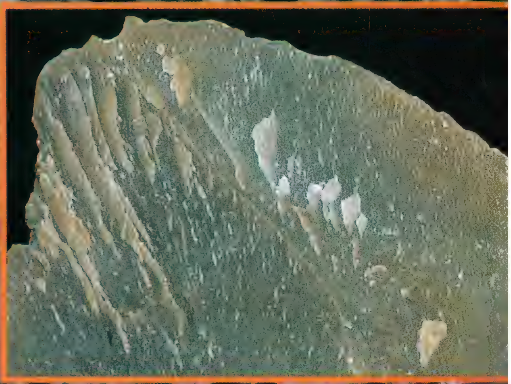
Fire opal *is one of the transparent, orangey-yellow varieties of opal – a type of silica crystal. Highly prized as a semi-precious gemstone, it is used extensively in jewellery.*



GSF Picture Library

A botryoidal *(grape-like) mass of haematite – a red or black mineral consisting of iron oxide. It is the most common iron ore but is only weakly magnetic.*

Talc *is a soft, greasy mineral, containing magnesium silicate. Apart from the popular talcum powder it is used in ceramics, paints, plastics and paper.*



GSF Picture Library

GSF Picture Library

Yellow crystals of *monoclinic sulphur – used in matches, gunpowder and sulphuric acid.*

GSF Picture Library

Lead sulphide *or galena is the most common ore of lead. The mineral is found in clumps of hexahedral (six-sided) crystals.*

Quartz *is a widespread mineral that is a major component of sands and sandstones.*

GSF Picture Library

GSF Picture Library

Sinclair Stammers/Science Photo Library

Copper pyrites *is an abundant copper ore. One of the first metals to have been used by humans, it is also one of the strongest pure metals.*

BOMB AIMING RANGE FINDING SILENT WEAPON

BEAMS IN BATTLE

Huge lasers *were built as part of the Star Wars programme. The aim was to launch them into space on satellites, where they were supposed to destroy incoming ballistic missiles.*

Alexander Tsiaras/Science Photo Library

LASER BEAMS HAVE ALWAYS conjured up the science fiction image of the death ray. But it is only very recently that they have had any real military application.

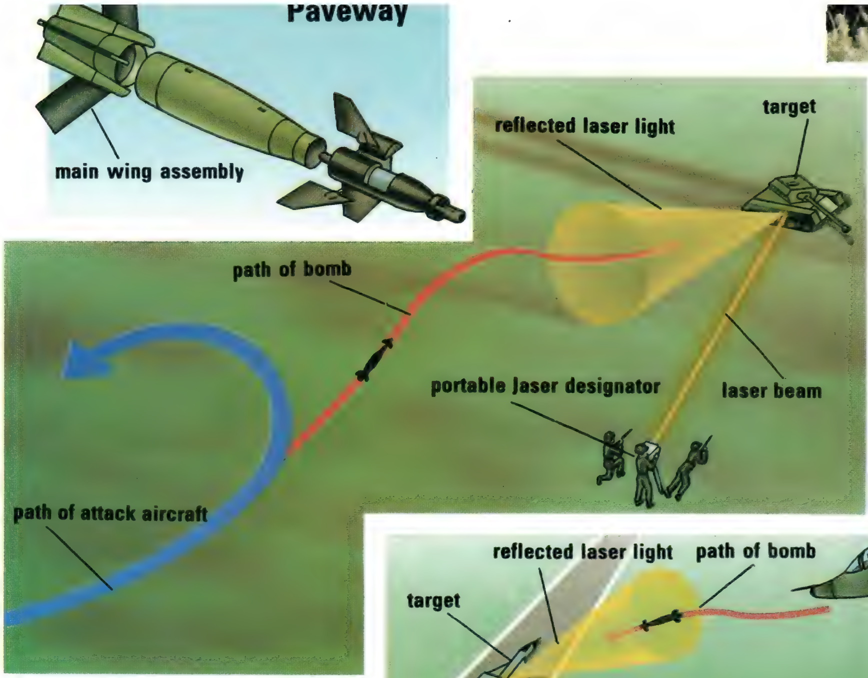
Modern armies now use lasers as target designators – usually known as laser target markers. When forward air controllers called in aircraft to provide close support to troops on the battlefield they often used to risk bombing their own men. A pilot flying perhaps as low as 100 ft. at 400 knots, who is being shot at, could easily make fatal mistakes.

The task of the forward air controller – the man who calls in air support – is made much easier by a laser target marker. Now all he has to do is get himself into a position on the ground where there is a direct line of sight between him and the target. He shines the laser beam directly on to the target. When the air support comes in, the pilot drops his bombs into the envelope of energy reflected from the target. Sensors in the nose of the bomb detect the source of the energy and home in on the target.

Easy accuracy

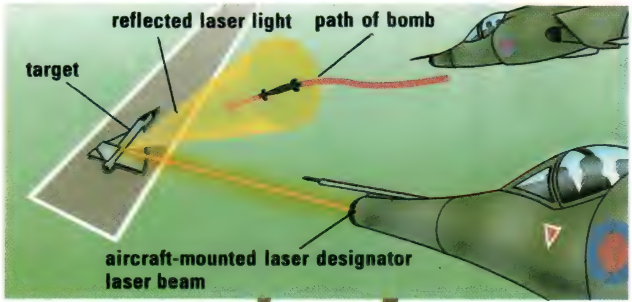
The bomb has no propulsion system so its trajectory can only be altered slightly. But laser target designation means that pinpoint accuracy is no longer required. The pilot only has to drop his bomb in the right area – an enormous advantage in battle.

Where a forward air controller



Mark Franklin

Ferranti/TRH Pictures



The guided bomb *Paveway has small steerable wings on its nose cone (top) which guide the bomb down the cone of laser light reflected from the target.*

The laser designator *must be in line of sight of the target. The forward air controller simply points the laser beam at the target. A bomb dropped in the general vicinity will then be guided home. Laser designators can also be carried in the nose of an accomapanying aircraft (below left).*

GEC Ferranti

cannot get within line of sight of the target, another aircraft with a laser designator mounted on it can pinpoint the target while a bomber delivers the high explosive.

Artillery forward observation officers also use laser target markers to guide 'smart' shells. This dramatically increases the effectiveness of artillery.

On target

In aircraft, laser equipment is also used to provide accurate target ranges. Bombs may be dropped automatically with remarkable precision, after a computer has made allowances for even minute variables such as wind speed and direction.

On land, too, lasers are used to gauge distances accurately. Before a tank fires its main armament, for example, it must be sure it knows the range of its target. Otherwise, with the curved trajectory of the projectile, it is likely to miss. Until very recently, tanks fired special ranging machine guns to estimate distance. These shot glowing tracer rounds that could easily be seen hitting, falling short or going high. When tracer was on target, the appropriate range was set and main gun fired.

But this procedure was time consuming and warned the enemy. Anyone seeing tracer coming knew what was coming next and took evasive action. Now though, at the press of a button, a laser range finder will give an instant readout of the distance to the target, leaving the enemy no time to move.

The Royal Navy has been using a laser weapon to defend its ships. Although British ships already had a number of anti-aircraft defence systems, including missiles and rapid-firing heavy machine guns, it was considered unwise to use such hostile armaments in sensitive situations.

Laser weapons were first fitted in 1986 to ships serving in the Armilla patrol in the Arabian Gulf where Britain played a key role in escorting merchant ships at risk from attack during the Iran/Iraq war. Each of the three navy ships serving in the Gulf had two laser weapons. More recently the devices have been fitted to ships serving in the Falklands.

Blinding light

The laser weapon sends out a powerful beam of light that at a range of 1 kilometre can temporarily blind an enemy pilot. This will force the pilot to abandon his bombing run or, if he manages to remain on course, to drop his bombs wide of the target. The system is not powerful enough to cause permanent damage to the eyesight and is designed to be used in situations where blowing an attacking aircraft from the skies is liable to provoke further hostilities.

In the early 1990s, following the break up of the Soviet Union and reduced threat of nuclear war laser research was directed towards developing a global defence system against the impact of asteroids from space.

Just amazing!

SHARP SHOOTING

LASERS ARE SO ACCURATE THAT A BEAM CAN HIT A TARGET 20 MM ACROSS - THE SIZE OF A SMALL COIN - AT A RANGE OF 2 KM.

Paul Raymonde

Q BUTTON CELLS
Q SOLAR CELLS
Q ELECTRIC CARS

POWER PACKS

Simon Bruty/Allsport

FROM THE TINY CELLS that run hearing aids and electronic watches, to the bulky batteries used to start cars, portable power is available in a variety of forms to serve every imaginable modern need.

A battery consists of one or more cells. Ordinary cells produce electricity on demand through a series of chemical reactions. They exploit the fact that many chemical reactions involve the transfer of electrons from one atom to another. An atom or group of atoms that carries an electric charge is called an ion.

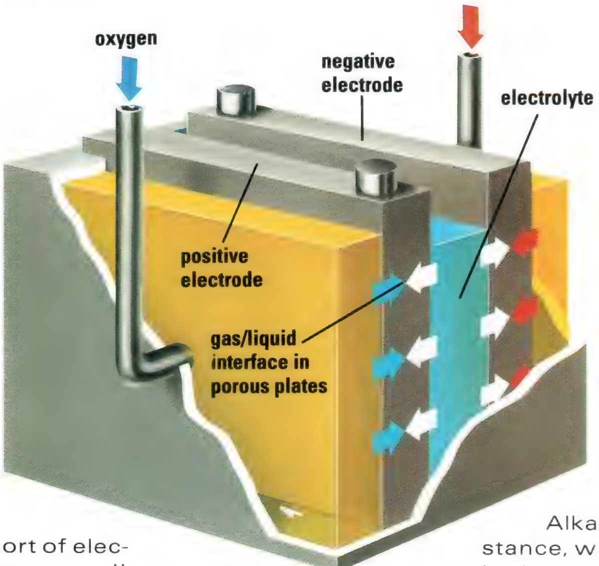
In a cell, ions are supplied by a chemical solution or paste called the electrolyte. Cells are made in such a way that negative ions – those with an excess of electrons – collect at one point, and positive ions, which are

__An array of solar cells__ can produce enough energy from sunlight to power an electric car (below left). The battery in a heart pacemaker (below) can last for up to ten years.

Science Photo Library

Black & Decker

Battery-operated tools *are convenient to use as there are no trailing mains leads. After use, this electronic screwdriver is attached to a wall-mounted mains unit to ensure that its batteries are fully charged when it is next required.*



short of electrons, collect at another point. These collection points, called electrodes, are in contact with the electrolyte. A terminal on each electrode allows the cell to be connected to a circuit. When this is done, a stream of electrons flows from the negative terminal to the positive. This flow of electrons is an electric current.

Standard cells

The most common type of cell is the zinc-carbon type. A carbon rod in the middle of the battery acts as the positive electrode, while an outer casing of zinc serves the dual purpose of container and negative electrode. Between the two electrodes is the electrolyte – in this case, a moist, conducting paste of ammonium chloride, zinc chloride, manganese dioxide and carbon particles.

In a cylindrically-shaped cell, the carbon rod, capped with steel, emerges as the positive terminal at the top. The bottom of the zinc casing, or a thin steel covering directly in contact with it, acts as the battery's negative terminal.

Increased output

A cell of this kind, whatever its size, will supply 1.5 volts. Making it bigger simply increases the maximum current that the cell can supply. Higher voltages are obtained by combining several cells in one battery. For instance, a 9-volt battery contains six 1.5-volt cells joined together in series, a 6-volt, four and so on.

Zinc-carbon batteries have the advantage of being cheap. But more expensive types of battery give better performance. Alkaline batteries, for instance, which use potassium hydroxide as the electrolyte, last longer. They also work more efficiently at low temperatures.

The miniature button cells used in electronic watches, hearing aids and some caculators and cameras employ layers of zinc powder and either mercury oxide or silver oxide as electrodes, with potassium hydroxide in between as the electrolyte.

Rechargeable cells

Most batteries have to be thrown away when they run down. But a nickel-cadmium battery, though marginally more expensive, can be charged up very cheaply over and over again. This is done by inserting it in a mains-supplied recharging unit.

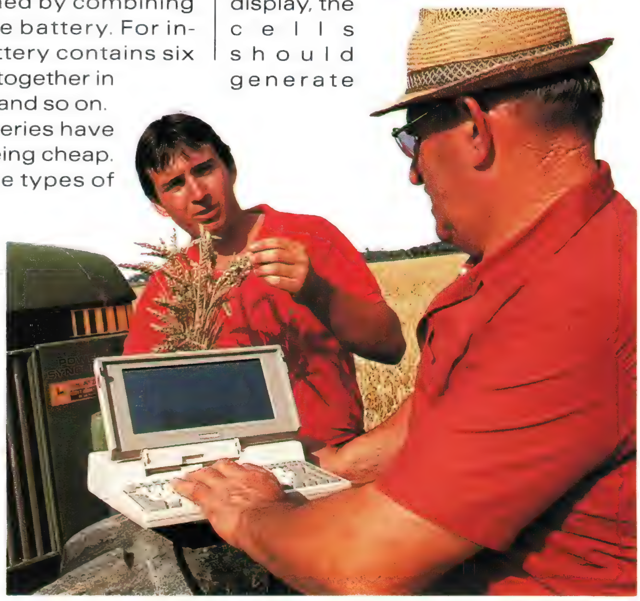
During recharging, an electric current flows through the battery in the opposite direction to normal. As a result, the chemicals in the electrolyte are once again returned to their original state, so the battery can once again supply current.

Solar cells

Some equipment runs on cells that last a lifetime but never need charging. Many pocket calculators, for example, are powered by solar cells. These convert the energy of daylight, or artificial light, into electricity.

Wherever there is enough light to see the numbers on the calculator's display, the cells should generate sufficient power to operate the electronic circuits inside.

Even experimental cars have been powered by solar cells, but a more promising power source for future electric vehicles is the fuel cell. This produces electricity by combining hydrogen and oxygen gases. Unlike today's petrol-powered vehicles, a car running on a fuel cell would not pollute the environment – the only waste product would be water.



Ivaldi/Jerrican

Portable lap-top computers *have revolutionized many fields of work. Data can now be entered directly, wherever it is collected.*

The fuel cell *may power cars of the future. In the type of fuel cell shown here, hydrogen and oxygen gases pass through the porous electrodes, combine with the electrolyte, and produce electricity in the process.*

Just amazing!

PURCHASING POWER

ELECTRICAL ENERGY FROM THE BUTTON CELLS USED IN ELECTRONIC WATCHES, COSTS ABOUT 175,000 TIMES AS MUCH AS POWER FROM THE MAINS.

Paul Raymonde

MICROWAVES

RADIO WAVES WITH A VERY short wavelength – or microwaves – were largely ignored by scientists until about 50 years ago. Yet today, they are used for diverse tasks from studying the origin of the Universe to heating up pizza in seconds.

Microwaves are used in radar, satellite communications, atomic clocks and cookers. Microwave energy is a type of electrical energy that can be transmitted through Space.

Tony Craddock/Science Photo Library

Jerry Mason/Science Photo Library

Communications

Microwave signals carrying television, telephone and computer data can be relayed by an orbiting satellite between two points on the Earth's surface. The microwaves are beamed up to the satellite – usually at

***An Earth-orbiting satellite** can, at any one time, handle two TV channels, 12,000 telephone conversations and computer data via microwaves. Communications between spacecraft and ground control use microwaves because of their ability to penetrate the Earth's atmosphere. One user is the European Space Agency's Operation Centre (above) in Darmstadt, Germany.*

a fixed position in the sky – from an Earth station – a large dish-shaped transmitter. Signals are boosted and shifted to a different frequency before being transmitted to a different part of the Earth's surface. The signals are picked up, by another large dish antenna for distribution to homes and workplaces, or, if the signals are powerful enough, they may be collected directly by small rooftop dishes.

On ground level, microwave links connect electronic news gathering (ENG) teams with their central television station. This avoids interference with longer radio waves that broadcast television and radio.

Microwaves for long-distance communications are generated by a device called a maser. Just as lasers give out bright, pure beams of light, so masers produce intense, narrow beams of microwaves at a single frequency. Masers work by energizing the molecules of certain crystals, liquids or gases, causing them to give off a flood of photons.

Masers

In an ammonia maser, for instance, excited molecules vibrate with a natural frequency of 24,000 million times per second. Introducing a weak input beam of exactly this frequency triggers a chain reaction in which large numbers of the excited molecules drop to a low energy state – in the process giving off an intense beam of 24,000 MHz (1.25 cm) microwaves. Because of this precision, ammonia masers are used as a frequency or time standard and form the basis of atomic clocks.

Radar

Being highly sensitive, masers are also used to amplify or detect electromagnetic radiation – including very weak radio signals in Space (see Cosmic waves box) and are used in long-distance radar systems.

Radar (Radio Detection And Ranging) bounces radio waves off distant objects. The radio waves are sent out in a sweeping, focused beam and the returning signal is detected by an antenna. They are used to calculate the distance, heading and speed of, for example, an aircraft.

Ordinary radio waves are too long to be able to 'see' clearly an object as

COSMIC WAVES

NASA

In 1965, American scientists Arno Penzias and Robert Wilson were studying natural sources of microwaves in Space that cause interference in telephone lines. They discovered a weak microwave 'glow' at a wavelength of 7.35 cm, coming from all parts of the sky. This cosmic microwave background is now believed to be the remains of the colossal explosion, or Big Bang, which formed the Universe.

A spacecraft called COBE (Cosmic Background Explorer) was launched in 1989 to carry out a two year study of the microwave background from Earth orbit. Two of COBE's detectors were chilled by liquid helium to within 2° of absolute zero so that they did not radiate more microwaves than they were trying to detect. These instruments were so sensitive that they could detect the power received by a postage stamp in London from a light bulb in Liverpool. From tiny variations in the cosmic background, astronomers hope to determine when and how the first galaxies formed.

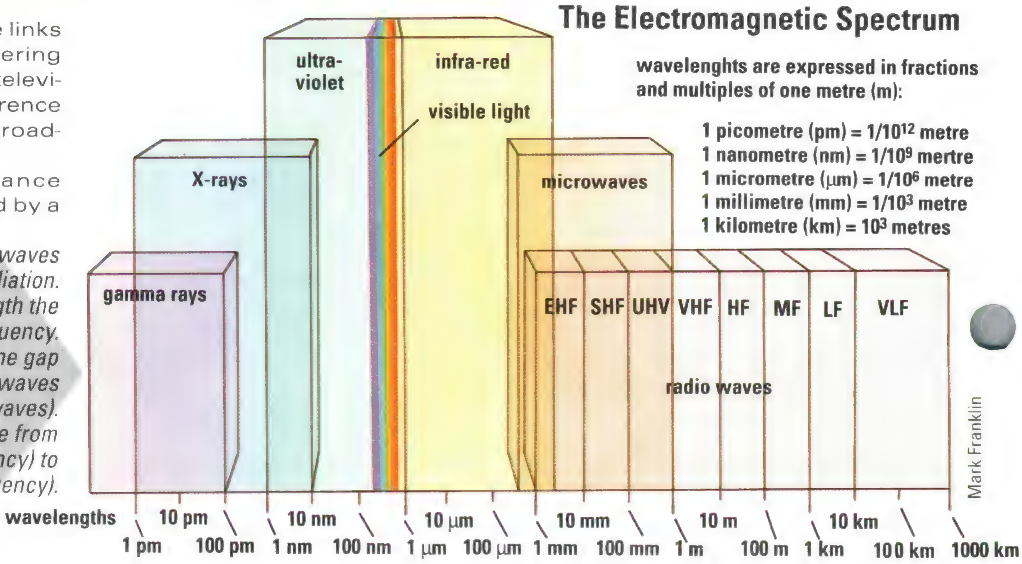
***A communications satellite** is born – launched in Space from the cargo bay of the American Space Shuttle* Discovery, *in 1985, to take up a fixed position in orbit around the Earth.*

NASA/Science Photo Library

***Fixed aerials** used for amplifying and relaying microwave signals are called repeaters. These must be spaced within line of sight, across country because microwaves are unable to pass through obstructions, such as hills or buildings.*

Telefocus

The Electromagnetic Spectrum



wavelenghts are expressed in fractions and multiples of one metre (m):

1 picometre (pm) = $1/10^{12}$ metre
1 nanometre (nm) = $1/10^{9}$ mertre
1 micrometre (µm) = $1/10^{6}$ metre
1 millimetre (mm) = $1/10^{3}$ metre
1 kilometre (km) = 10^{3} metres

***The Sun emits energy** as waves of electromagnetic radiation. The longer their wavelength the shorter their frequency. Microwaves bridge the gap between normal radio waves and infra-red (heat waves). Radio frequencies range from EHF (extra high frequency) to VLF (very low frequency).*

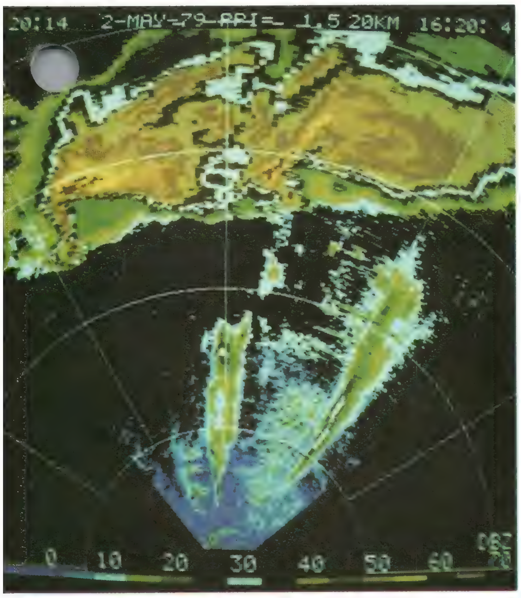
Mark Franklin

James Stevenson/Science Photo Library

Radar equipment *onboard the* H M S Yarmouth *alerts the ship to the range and bearing of the coastline and location of other vessels in the surrounding area.*

James Nettis/Science Photo Library

Radar consoles *in the control room at Philadelphia International Airport, USA, show aircraft flight maps and warn of weather problems. Radar, in conjunction with advanced instrument landing systems, can land aircraft fully automatically if required.*



NCAR/Science Photo Library

A tornado *developing in Northern Oklahoma, USA, shows up on a radar display screen as a brown/yellow peninsular area to the left of this picture.*

small as an aeroplane. Microwaves have a shorter wavelength and hence a greater ability to resolve detail.

Storm warning

Microwave beams from an airliner's weather radar allow a pilot to see many kilometres ahead to spot storms. Microwaves pass straight through clear air and ice crystals. But water droplets, or hail with a film of rain water, partly reflect the radar beam, creating echoes that show up on a radar screen. These echoes are processed by computer and colour-coded so that areas of heavy rain appear red, while those of lighter rain show as yellow or green. If the radar data indicates a thunderstorm ahead, the pilot will call ground control for permission to chart a course around it.

The magnetron

Very long-distance radar uses masers to generate microwave signals but most radar systems employ a simple device called a magnetron. Inside a magnetron, a negatively charged electrode, in the centre of a vacuum-filled space, acts as a source of electrons.

The electrons (tiny negative charges), are drawn across the airless gap by the positive charge on a surrounding electrode. At the same time, the electrons are influenced by a powerful magnetic field. This makes the electrons spiral rapidly as they move outwards, causing them to give off microwaves. The shape of the gap and the strength of the magnetic field determine the precise frequency of the microwaves given off.

A magnetron is also the main component of a microwave cooker used to cook and heat food and also thaw it from frozen. Microwaves themselves contain no heat. It is their effect on water molecules that in turn heats food (see box p134).

Core temperature

Microwaves are reflected by metal, are partly absorbed by water and pass straight through non-metallic substances such as plastic. All inner surfaces of the microwave cooker are metallic to reflect microwaves towards the food placed inside.

Because they are absorbed by water molecules, microwaves penetrate food to a depth of only 5 cm. The centre of a large piece of meat is cooked by heat conducted from the outside – just as your hands heat up when you rub them together. Tests on pre-cooked meals have shown microwave cooking to be less effective with salty food. Salt contains ions (charged atoms or groups of atoms) that flow under the influence of the electric field of microwave radiation. This stops the microwaves penetrating food sufficiently to heat it to a temperature that kills the organisms that can cause food poisoning.

Microwaves may be the key to long term food preservation. Food could be effectively sterilized by heat-

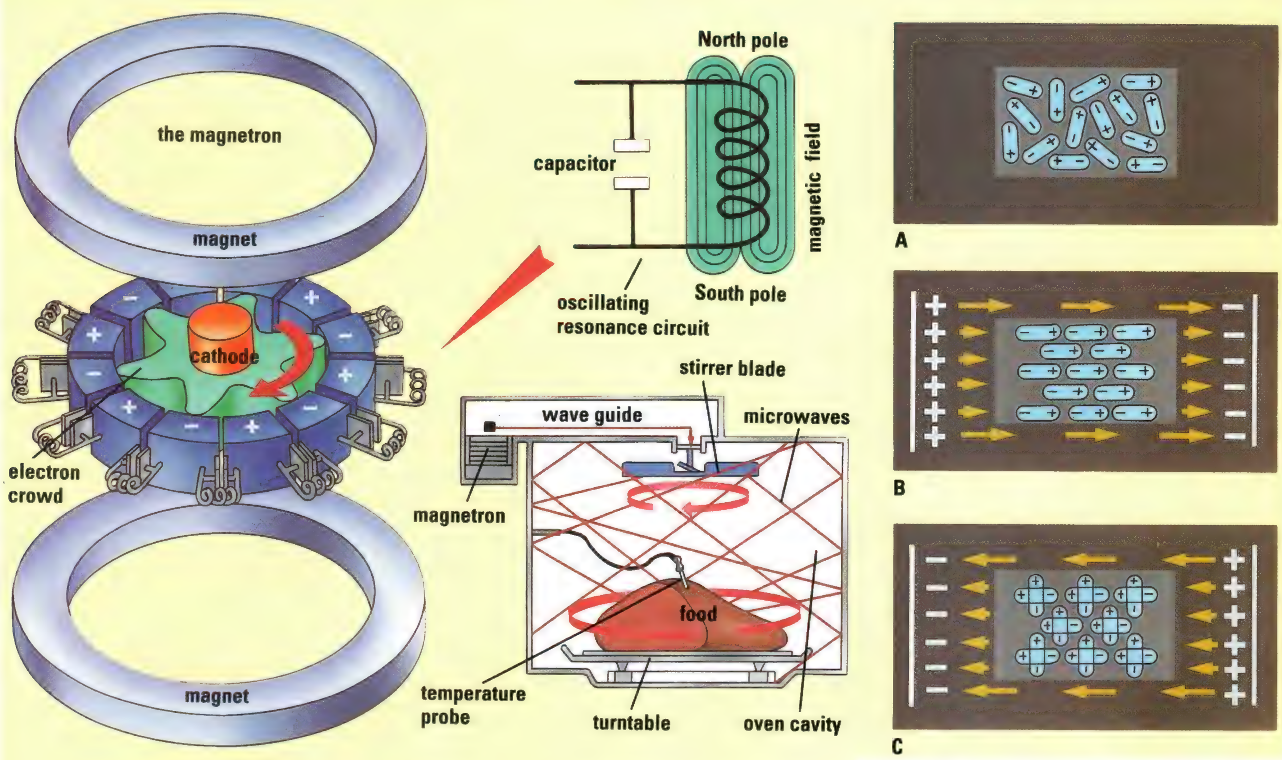
Just amazing!

TIME-KEEPING

THE WORLD'S MOST ACCURATE CLOCKS ARE BASED ON TWO HYDROGEN MASERS AT THE US NAVAL RESEARCH CENTRE IN WASHINGTON, USA. THEY KEEP TIME TO WITHIN 1 SECOND IN 700,000 YEARS.

Paul Raymonde

THE BASIC PRINCIPLE OF MICROWAVE COOKING



At the core of a microwave cooker is a magnetron. Inside, a heated cathode, within a magnetic field, emits electrons that crowd and spin outwards. In passing the tips of the resonance circuits the electrons cause rapid positive and negative field reversals that in turn produce microwaves.

Water molecules have two magnetic poles (one positive and one negative). These molecules are randomly arranged in food (A) until aligned by applying an electrostatic field – microwaves (B). Alternating the field rapidly 'flips' the molecules (C) causing frictional heating that cooks the food.

Mark Franklin

Peter Menzel/Science Photo Library

Experimental treatment of tumours using microwaves relies on the fact that cancerous cells are more easily destroyed by heat than normal tissue.

ing it to 250°C for three minutes to kill all harmful bacteria, before sealing it in bacteria-free packages. This would increase the shelf life of some foods to years rather than days.

Destroying tumours

One very important development in the application of microwaves is in the field of medicine. It has been discovered that cancerous tumours are killed by heating them to 109°C. Some success has been achieved with microwave treatment of patients whose cancerous cells are on or close to the surface of the skin.

Efforts are continuing to find how to heat tumours consistently and to accurately measure the temperature of tumours being treated. Work is also being carried out to reduce side effects that include burns and blistering.

MICROWAVE PLANE

Daudier/Jerrican

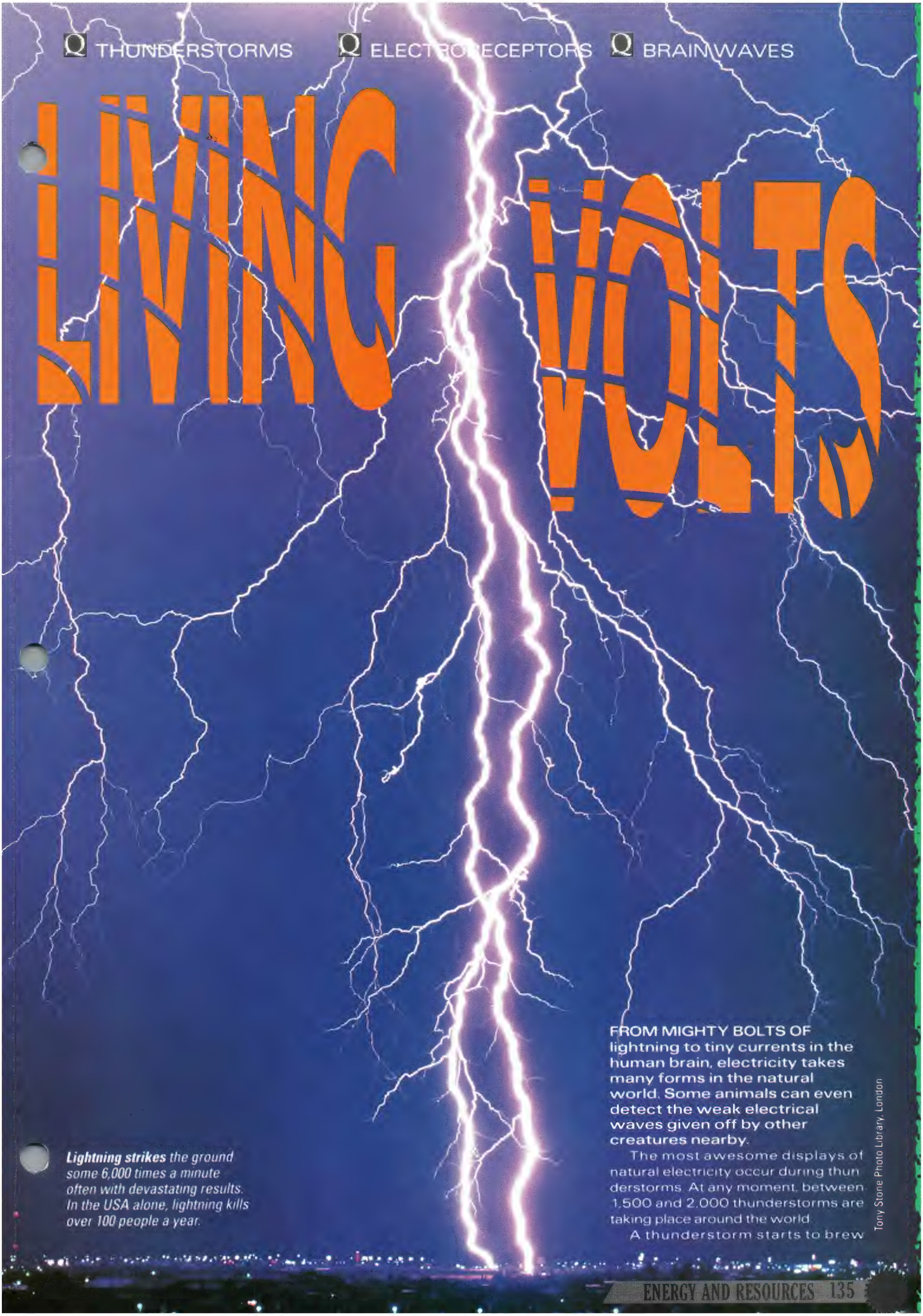
This is the world's first pilotless, microwave-powered aircraft. An operational prototype being developed from the test model, in Canada, at a cost of some £15 million, will have a fuselage 24 metres long and a wingspan of 36.5 metres. Powered by about 12 transmitters onboard and controlled from Earth, the craft will fly at twice the height of most conventional aircraft.

The microwave craft will be less expensive to operate – at around £125,000 per year – than the largest telecommunications satellite. It will also be more powerful than any satellite and capable of uninterrupted and easily controlled flight – allowing it to be brought back to Earth for data collection and repairs.

Kitted out with a transmitter the craft could serve an area 600 km in diameter. Alternatively the craft could be ideally suited to help study pollution. It could, for example, measure levels of sulphur dioxide and nitrogen oxide in the atmosphere from an altitude of 120 metres.

THUNDERSTORMS ELECTRORECEPTORS BRAIN WAVES

LIVING VOLTS



Tony Stone Photo Library, London

Lightning strikes the ground some 6,000 times a minute often with devastating results. In the USA alone, lightning kills over 100 people a year.

FROM MIGHTY BOLTS OF lightning to tiny currents in the human brain, electricity takes many forms in the natural world. Some animals can even detect the weak electrical waves given off by other creatures nearby.

The most awesome displays of natural electricity occur during thunderstorms. At any moment, between 1,500 and 2,000 thunderstorms are taking place around the world.

A thunderstorm starts to brew

Julian Baum/Science Photo Library

Scientists are sceptical about the existence of ball lightning, but there are many eye-witness accounts. Glowing spheres up to a metre across have been seen inside closed rooms and even aircraft, as well as in the open air.

Bead lightning *above Los Alamos, New Mexico, USA. Sometimes the main lightning flash breaks up into luminous sections, or 'beads', as it fades.*

when a mass of cold air moves on top of a body of hot, humid air. Violent up and down draughts tear at the water droplets, ice crystals, and hailstones inside the developing storm-cloud, causing static electricity to build up.

Giant battery

Smaller particles, carrying a positive charge, rise to the top of the cloud. At the same time, larger, negatively-charged drops and hailstones gather at the cloud's base. This separation of charge effectively turns the cloud into a giant battery capable of generating a sudden, enormous spark. Underneath the cloud, a positive charge is induced at ground level. A cloud-to-ground lightning flash begins with an invisible discharge, called a leader, that branches downward. This carries a negative charge towards the Earth's surface and creates a trail of ionized air (ions are atoms that have been charged by stripping their electrons).

Discharges

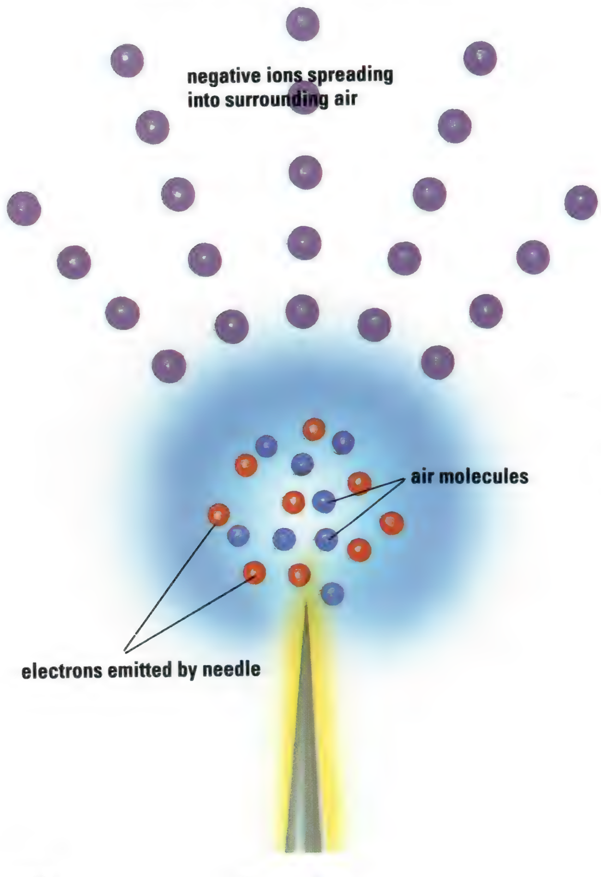
As a branch of the leader comes to within roughly 100 metres of the ground, the negative charge in the air attracts the positive charge near the ground. Discharges then form at the ground and travel upwards until they meet the leader. When contact is made, the first bright return stroke occurs. This is the start of the lightning strike. The return stroke, with a peak current of between 10,000 and 40,000 amps, races back up the trail of ionized air into the cloud.

The leader

After a pause of a few tens of micro-seconds, another leader comes down, triggering a second return stroke. Most lightning flashes consist of three or four leaders and return strokes, though as many as 40 have been observed. The bright flash we see comes from the upward moving return strokes.

Sometimes a leader travels only part of the way down an existing ionized channel, then forges a different

How an Air Ionizer Works



Mark Franklin

Ions are tiny electrically charged particles in the air; negative ions are air molecules that have acquired an extra electron. When the level of negative ions in air indoors and in cities is increased, people become less tense and more alert. Negative air ions can be created in an air ionizer by sending high voltage electrical charges through one or more needles. High velocity electrons are emitted by the electric field at the tip of the needle.

Andy Best/Met Office

One flash *of cloud-to-ground lightning strikes at one two-thousandth the speed of light with a power of up to 200,000 amps. This tree in Utah, USA, was struck by such a force.*

ELECTRIC EELS

Hans Reinhard/Bruce Coleman Ltd

The electric eel of South America is one of the few creatures in the world that can kill its prey by electrocution. Measuring up to 2.5 metres in length and 22 kg in weight, the electric eel has three pairs of electric organs on each side of its body. These living batteries can produce either a continuous, low-voltage discharge to help sense the surroundings or a sudden shock, strong enough to stun a man. At full strength, the eel can generate 650 volts, usually in three to five bursts lasting about two thousandths of a second.

path to the ground. In such cases, forked lightning is seen. On other occasions, discharges take place between neighbouring clouds without reaching the surface at all. This gives rise to sheet lightning.

Because lightning usually seeks out the highest object, tall or isolated trees and exposed hill tops are especially dangerous places to be in a thunderstorm. Metal structures are also a hazard.

Blue sparks

In 1955, at the racecourse in Ascot, southern England, lightning ripped along metal railings in a series of blue sparks that jolted nearby spectators over a metre into the air. Two people were killed and 47 were injured.

Metal jewellery, such as a medallion, has been known to draw lightning. Even making a phone call during a thunderstorm has its risks. In 1988, a woman in Sheffield, England, was burned on her ear and thigh when lightning struck the telephone wires and passed through her body.

Ball lightning

A single flash can carry over 10,000 amps at 30,000°C – more than enough to reduce human flesh and bone to ashes. Whether or not a lightning strike is deadly, depends on the path it takes through the body to the ground. About three-quarters of those who are struck suffer only burns. However, if most of the current passes through a major organ, such as the brain or heart, it can kill.

Less common and more mysterious than ordinary lightning is ball lightning. This occurs during thunderstorms, though it has been seen in fair weather too. A typical 'ball' measures some 25 cm across and glows a pale red or orange colour. It may have a halo around it or give off sparks. Ball lightning can last for a minute, or even longer, before either exploding violently or simply fading away.

Strangest of all, ball lightning has a habit of seeking out the insides of buildings or aircraft. Witnesses report having seen it floating around the rooms of a house, steering clear of the furniture, before disappearing up the chimney or out of the door.

So far, scientists have failed to fully explain this phenomenon. It is likely that the ball contains plasma, or highly ionized gases at high temperatures. But the mechanism by which such a large amount of energy can be contained in such a compact form for so long is not well understood.

Natural electricity on a much smaller scale is vital to the functioning of our bodies. Electrical signals travelling along nerve cells to and from the brain allow us to sense our surroundings and to respond by moving muscles. An individual nerve impulse registers less than a tenth of a volt and travels at a speed of up to 100 metres per second. This means that the longest delay for an impulse making a round trip between the brain and any part of the body is less than 0.04 of a second.

Each nerve cell, called a *neuron*, is

***Testing** for deafness. A device called the Nicolet Pathfinder measures tiny changes in the brain's electrical activity caused by sounds sent through the baby's headphones. The changes are recorded by an EEG. By comparing the output (seen on screen) with 'normal' results, hearing problems can be identified.*

Alexander Tsiaras/Science Photo Library

***An electric ray** stuns the fish on which it preys with a powerful electric current produced by organs in the head and back. This can measure up to 220 volts.*

Roy Manstan/Planet Earth Pictures

***The platypus,** found only in eastern Australia and Tasmania, locates its prey by detecting the weak electric fields radiated by other animals with its leathery, sensitive, duck-like bill.*

ANT/NHPA

SAFETY TIPS IN THUNDERSTORMS

Gamma/Frank Spooner Pictures

If you are outside:
- Run for shelter (a building or car) but avoid small sheds or tents in open areas
- Stay clear of tall objects such as trees, telephone poles and boat masts
- Get out of and away from water
- Avoid metal objects, such as traffic signs, posts and fences
- If you are with a group of people, make sure you are at least 10 metres away from each other
- Squat with your knees tucked together. Do not lie on the ground!

If you are inside:
- Do not stand or sit near doors or windows
- Turn off TVs, stereos, computers and radios and do not use the telephone
- Do not take a bath or shower, or wash anything in the sink.

like a tiny, insulated wire. The nerve impulse moves along the narrow conducting fibre in the centre. A surrounding sheath made of the protein myelin acts in the same way as plastic insulation around an ordinary electric wire.

The end of each neuron branches out into many tiny pathways, known as *dendrites*. These are separated from the dendrites of neighbouring neurons by narrow gaps called *synapses*. For the short hop across a synapse, signals are transferred chemically rather than electrically.

The greatest concentration of neurons – about 10 billion of them – is in the brain itself. Millions of electrical impulses criss-cross the brain each second, even while we are asleep.

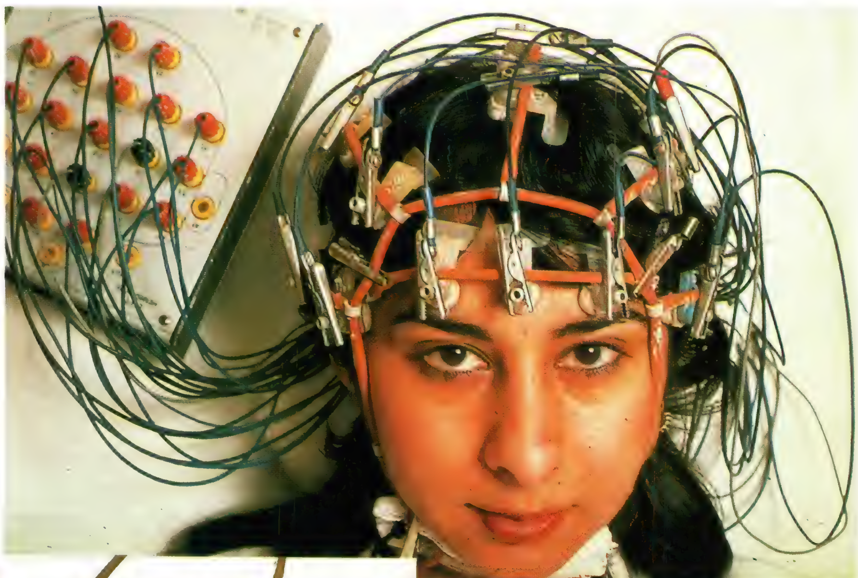
Collectively, these impulses are responsible for all our thoughts, memories and sensations.

Weak electric fields are produced by all living creatures as well as by many non-living objects – streams of water, for instance. Some animals, such as the duck-billed platypus, are equipped to sense these fields,which help them to navigate and find food. The side of its bill is lined with a number of electroreceptors that react to impulses as low as 20 millivolts (thousandths of a volt) occuring at a rate of up to 600 per second.

Electrical signals

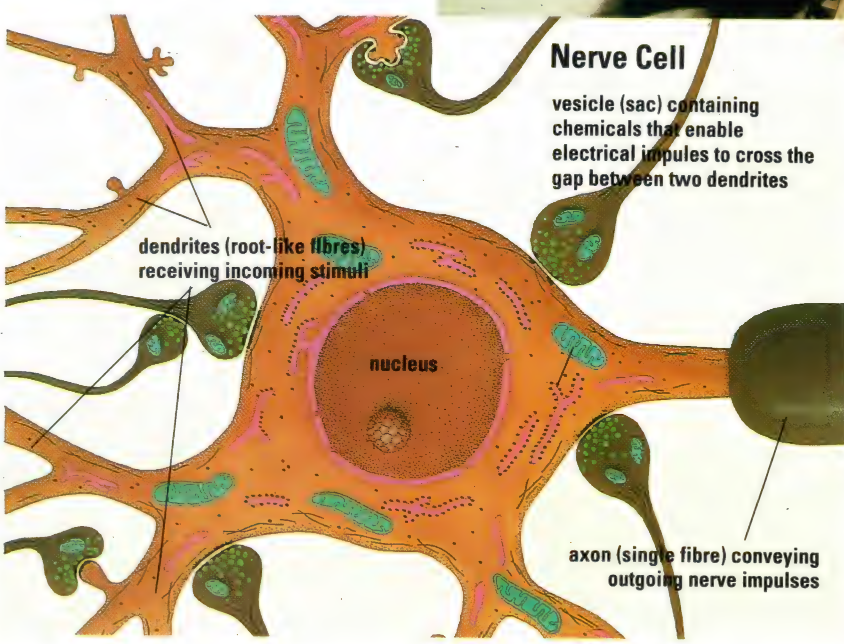
This means that the platypus can sense, for example, the tiny electrical signals passing between nerves and muscles in the tail of a shrimp – a favourite prey. The snout of the spiny anteater, another Australian mammal, can also detect electrical waves.

Sharks, and certain other fishes as well, have electroreceptors in their bodies. The shark's face is pitted with hundreds of minute holes, called the ampullae of Lorenzini, which can pick up the electrical waves radiated by fish swimming nearby.



Jerry Mason/Science Photo Library

Electric currents that pass through the brain can be recorded by an EEG, properly called an electroencephalograph.



Francis Leroy, Biocosmos/Science Photo Library

Electric impulses, sent from one nerve cell to the next, travel to the brain with information about the body's surroundings, then out again with instructions on how the body should react.

Just amazing!

THE BIG HEAT

A FLASH OF LIGHTNING CAN REACH TEMPERATURES AS HIGH AS 30,000°C – MORE THAN FIVE TIMES THE HEAT OF THE SURFACE OF THE SUN.

Paul Raymonde

NATURAL ATTRACTION

AT THE HEART OF MODERN technology such as motors, videotape recorders and atom smashers lies one of the fundamental natural forces: magnetism.

In ancient times it was known that a type of iron ore called magnetite attracts certain metals, such as iron, nickel and cobalt. Magnetite was once commonly called lodestone, which means 'guiding stone', because it was discovered – originally by the Chinese – that if a light, thin 'needle' of magnetite was pivoted, it would always swing so that it pointed roughly in a north-south direction. The end that is attracted to the north is called the magnet's north pole; the end that

David Parker/Science Photo Library

ZEFA

A particle detector *at the European Centre for Particle Physics near Geneva. Subatomic particles are bent into a curved path by the magnetic field and are then smashed together.*

The magnetic field *of a bar magnet is shown by iron filings that group along the lines of force, forming closed loops around the poles.*

is attracted to the south is called the magnet's south pole. Every magnet has two such poles. The magnetic attraction seems to be centred in them. If a bar-shaped magnet is dipped into iron filings, they will cluster around its poles – few will cling to the central part of the magnet.

Magnetic attraction

If a magnet is cut in half, new poles will appear, so that each of the pieces has both a north and a south pole. If the two pieces are put together, pole to pole, the opposite poles will cancel each other out. The two combined will be just the same as the single original magnet.

A magnetized piece of iron is divided into millions of regions called 'domains', typically from 1/100 to 1/10 cm across, and visible under the microscope. If these tiny 'magnets' point the same way, their magnetism will combine, making the whole piece of iron into a magnet. If they become disordered, pointed in all directions, they will cancel each other out. Though each domain continues to be a small magnet, the iron as a whole loses its magnetism.

If you place two magnets close to each other, you will soon find that their north poles repel each other (push each other away), while the north pole of one attracts the south pole of the other – 'like poles repel, unlike poles attract'.

Wandering poles

We know that the Earth behaves like a magnet from using a compass, therefore the Earth also has north and south magnetic poles.

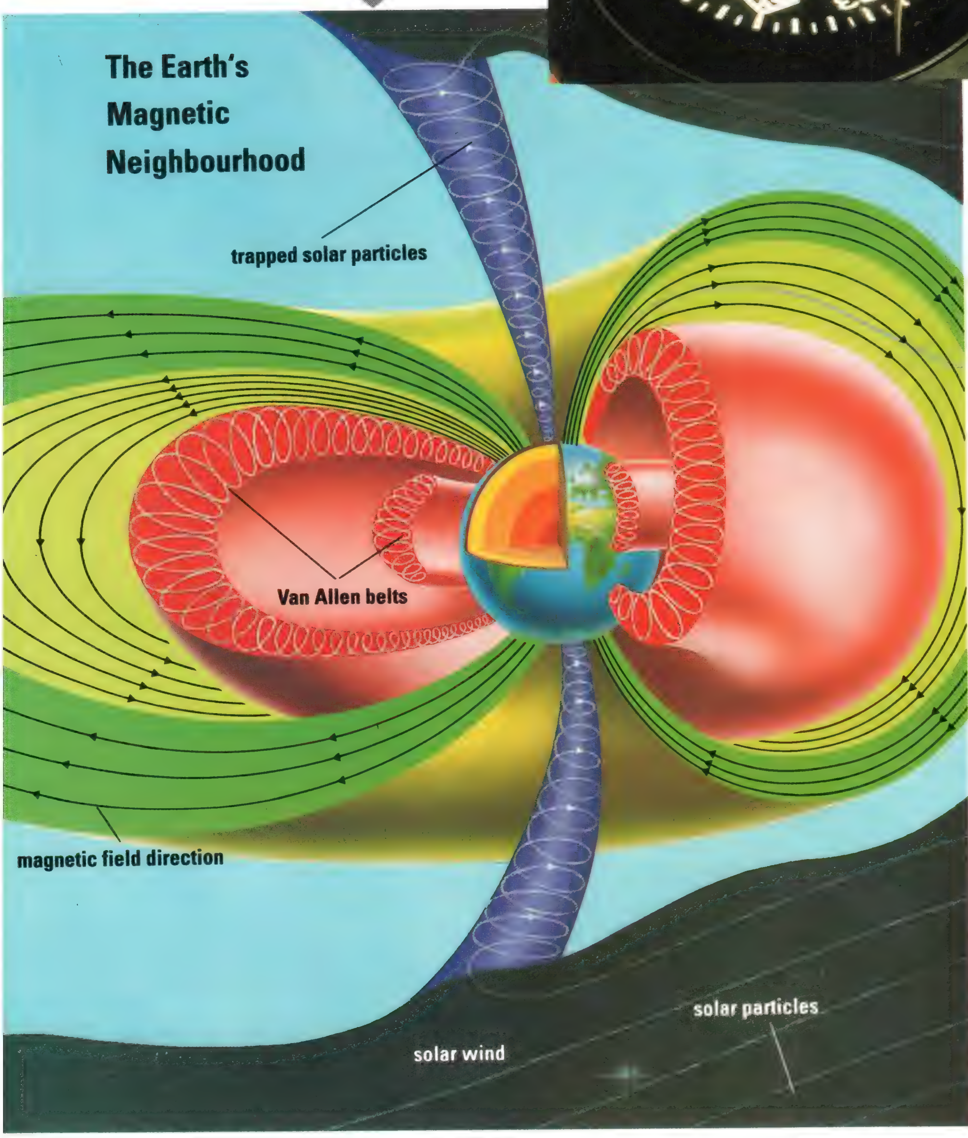
These 'geomagnetic' poles lie 1,400–2750 km from the geographical poles at present, but they wander erratically around over the course of centuries. (Since the north magnetic pole attracts the north-seeking end of a compass needle, and since unlike poles attract, it is itself a south-seeking pole!)

A magnetic compass is useless anywhere near the geomagnetic poles. Even elsewhere, it is necessary to know the magnetic 'declination' – the angle between true north and the direction shown by a compass. This information is recorded in tables or on maps, that have to be updated every year.

The influence of a magnet may be pictured by means of 'lines of force'. At every point around the magnet the direction of the line of force through it shows the direction of the magnetic force – as shown, for example, by the

C-Plath

***A mariner's compass** showing a 360° conical card that rests on a jewelled bearing in a bowl filled with liquids. The pointer, at approximately 330°, shows the sailor his compass bearing.*



Nick Farmer

***The Earth's magnetic field** – the magnetosphere – is distorted by the solar wind. Charged particles from the Sun are trapped in spiral paths in radiation belts known as Van Allen belts.*

ZEFA

***A levitating magnet** above a superconductor. The powerful magnetic fields created by superconductors can be used as the basis for magnetic levitation – MAGLEV – trains.*

Boxmag-Rapid Ltd

__Industrial magnets__ use a powerful electromagnet to lift bundles of bars. The electric current is switched off to release the load once it is in position.

direction in which a small magnetic compass placed at that point would lie. The direction of the line is defined as being from the magnet's north pole toward its south pole.

Lines of force spread out from a magnet's north pole, loop around it, then vanish into its south pole. They are crowded together where the magnetism is strongest. The pattern formed by these lines of force is known as the 'field' of the magnet.

One of the most momentous discoveries in the history of science was that electric currents create magnetic fields. Imagine a wire stretching vertically up out of this page. Imagine further that the Earth's magnetic field is shut out by enclosing the experiment in a metal cage. Now an electric current is switched on in the wire. The current consists of a stream of tiny particles called electrons, moving upwards along the wire.

Eriez Magnetics UK Ltd

__Recycling__ metal, from shredded waste, is easily achieved by magnetic drum separators. The metal is then added to new iron or steel ingots in a furnace.

Henry Dakin/Science Photo Library

__A Kirlian photograph__ of an electric discharge. This 'artificial lightning' has been created by dropping a small steel ball into a high-energy electrical field.

Circular field

A small compass placed close to the wire will turn until it is pointing along the circumference of a circle centred on the wire. When the field lines are mapped with the aid of the compass, or with iron filings scattered on the page, they are found to be circles centred on the wire. Since they do not come together or spread out, this magnetic field has no poles. However, the field grows weaker farther away from the wire.

The wire can be made into an electromagnet that mimics a bar magnet. It is looped many times into a cylindrical coil and the magnetic fields of all the turns of wire add together to produce a field like that of a bar magnet. Such an electromagnet is convenient, since it can be turned on and off. And the more turns of wire it has, and the larger the current through the wire, the more powerful the electromagnet. It can be made more powerful yet by winding the coil round a piece of iron.

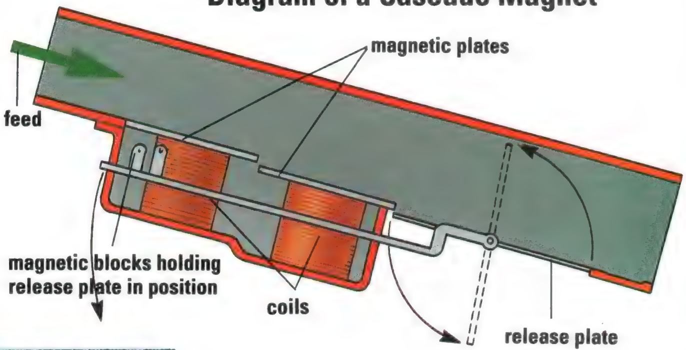
Atom smashers

Electromagnets are used for handling iron, steel and other magnetic metals. In scrapyards, for example, cranes equipped with electromagnets instead of hooks are used to pick up cars. Electromagnets are also used in giant metal shredders to separate scrap made of magnetic metal from other sorts of scrap.

Powerful electromagnets guide subatomic particles in accelerators ('atom-smashing' machines) used in nuclear research to investigate the

Mark Franklin

Diagram of a Cascade Magnet



__A Cascade Magnet__ is used to remove metal contamination from dry, free-flowing materials. Its soft iron core is magnetised when electric current is passed through the wire coiled around it. Unlike permanent magnets, the electromagnet loses its magnetic properties when the surrounding current is stopped.

GAMMA RAYS

The first blow in a nuclear attack could consist of a wave of gamma rays – a type of electromagnetic radiation. If a one-megaton hydrogen bomb (an average-sized nuclear weapon) were exploded in Space, about 400 km high, a pulse of gamma rays would flood the Earth below. These would not threaten life directly, but would knock out electrical equipment.

If the bomb were exploded above the central United States, unprotected electrical and electronic equipment from the East coast to the West Coast would be affected. Military equipment can be specially protected against this EMP (electromagnetic pulse), but civilian equipment, especially radios, televisions and computers, would be heavily damaged at a single stroke – and before the first bomb had gone off at low altitudes.

MAGNETIC STORMS

Magnetic compasses occasionally go awry, swinging back and forth, away from the true direction of magnetic north. At the same time radio transmissions may be disturbed, and power supplies may be disrupted. The cause lies 150 million kilometres away, in the Sun. Such a 'magnetic storm' is triggered some hours after a burst of high-energy particles has been fired into Space by a solar flare, a huge explosion on the Sun. The particles arrive at the Earth and are caught in the two Van Allen radiation belts – stores of trapped particles 10,200 km and 23,600 km high. This sudden flood of particles causes some of the contents of the belts to spill over and spiral down towards the magnetic poles along magnetic lines of force. As they do so they create wildly fluctuating fields that disturb compasses and generate stray voltages in electrical equipment.

many particles within the atom. The particles circulate around giant 'racetracks', such as one near Geneva that is 27 km in circumference.

They move at close to the speed of light, being boosted electrically on every 'lap', so that they pick up more and more energy. Finally they smash into a target, such as a block of metal, or are 'collided' with another beam of particles. The particles are forced to follow their curved paths by magnetic fields up to 20,000 times as strong as the Earth's. The electromagnets producing the field have to be positioned to within a fraction of a millimetre.

Electric currents

The Earth is not just a magnet but an electromagnet. Geomagnetism is caused by electric currents flowing in its iron core. The central core is crushed by huge pressure into a solid form, but the outer core is liquid iron. Hot fluid iron rises from deep in the outer core, cools and sinks again.

Combined with the rotation of the Earth, this results in a steady but complicated flow of fluid iron. This causes electric currents to flow in the core and create a magnetic field.

The Earth's field is very poorly understood. In particular, it is not known why it should fade away and then reappear, pointing the opposite way roughly every half-million years.

Sound and pictures

Magnetism is an important means of recording sound, video pictures and computer data. An audio tape consists of a thin film of polyester coated with a binder through which are dispersed needle-shaped particles of iron oxide or chromium dioxide.

When a sound recording is made, the tape passes close to a recording head, which contains an electromagnet. The strength of the current through the recording head, and hence the strength of its magnetic field, varies according to the strength of the sound that is being recorded.

Four track recording

The field from the recording head magnetizes a small section of the magnetic oxide coating. Where the field is strong the particles of the coating become strongly magnetized. As a result a pattern of strong and weak magnetization extends in a track along the tape. This pattern is a 'picture' of the sound waves that struck the recording microphone. There are four tracks, one pair in each direction. One track of each pair is for the left, the other for the right, stereo channel.

When the tape is played back, it moves past a coil similar to an electromagnet. The magnetic field from the tape passes through the coil, constantly fluctuating in strength. Such a varying field makes electric currents flow in the coil. These are boosted and drive loudspeakers, creating sound that is a copy of the sound that struck the recording microphones.

Recording a videotape works in much the same way, except that in addition to a track for the sound channel, the picture signal is laid down in a series of thin diagonal stripes, in order to pack in the vast amount of information that is needed to represent a television picture. A television picture represents an image as lines of dots. The pattern of magnetization on the videotape corresponds to those dots.

Auroras occur mostly over polar latitudes and are caused by the collision of air molecules in the upper atmosphere with electrically charged particles from the Sun.

National Centre for Atmospheric Research

Magnetic tape is used for sound recording. The tape consists of a layer of powdered magnetic material, which registers the signals to be reproduced later as sound.

Molinare

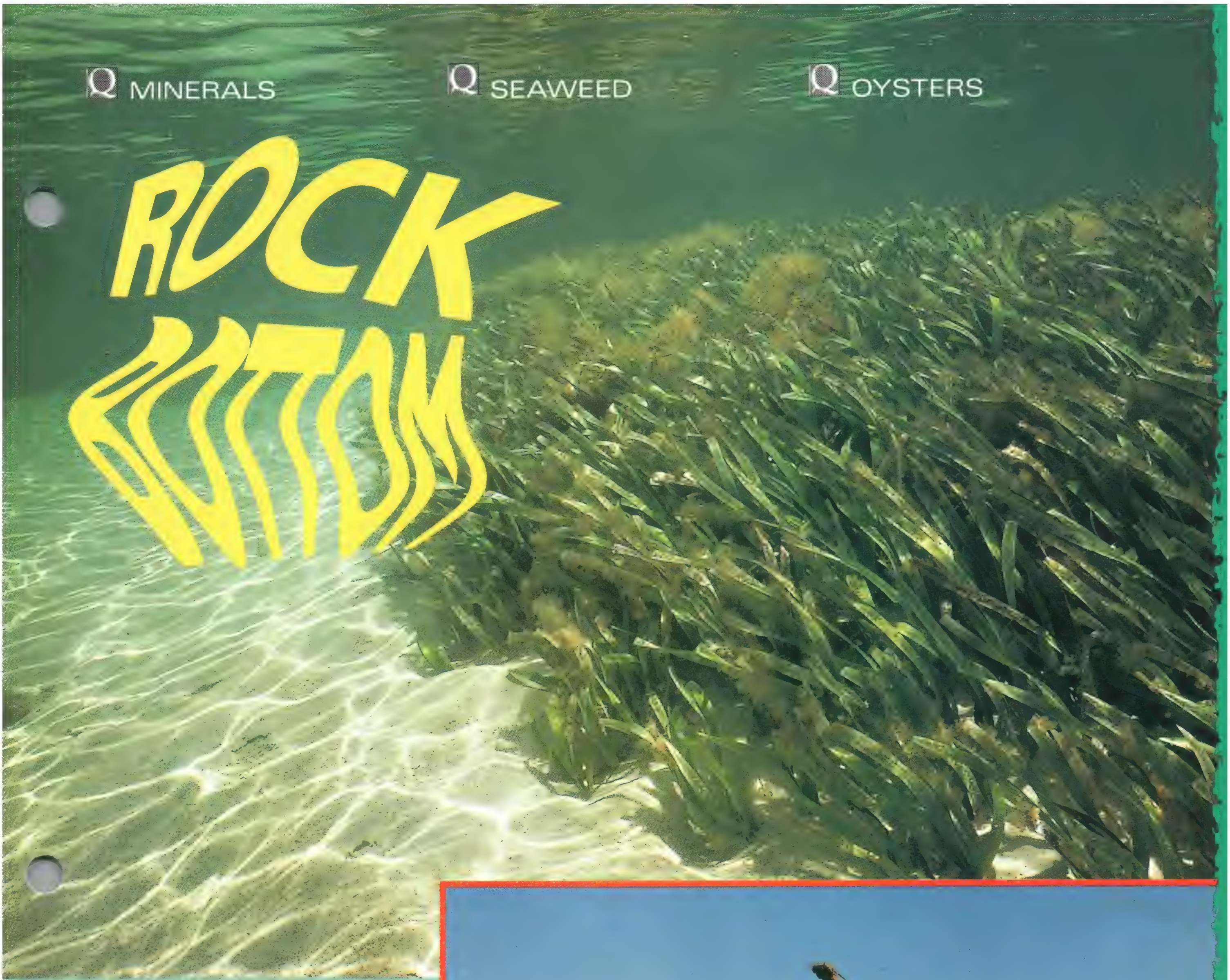
Just amazing!

HUMAN MAGNETS

IN 1920 INMATES OF A PRISON IN NEW YORK, USA, WHILE SUFFERING FROM FOOD POISONING, WERE REPORTED TO BE ABLE TO DEFLECT COMPASS NEEDLES AND ATTRACT METAL.

Paul Raymonde

ROCK BOTTOM



Patrick Baker/Bruce Coleman Ltd

THE SHALLOW BEDS OF seas around the world are rich in a variety of useful minerals, animals and plants. But harvesting these resources can present a challenge to both men and machines.

Seabeds are the source of much of the sand and gravel needed for the building industry. Britain alone uses about 100 million tonnes annually, of which 10 per cent is pumped from the shallow waters of the continental shelf by dredgers and dumped into waiting barges. Major deposits of shells, such as those off the Bahamas, are also mined extensively as a source of lime for agriculture or for use in making cement.

Metal deposits

Being heavier than other rock fragments, metals tend to concentrate on the seabed. Rain and wind erode metal ores on land, and rivers then carry the particles of ore into the sea. The heavy specks of metal settle out of the water first, forming metal-rich sands called placer deposits. These usually start off as beach deposits, but as the sea-level changes and shorelines move with time, many placer deposits are now found situated on the continental shelves.

Like sand and gravel, they can be mined by dredging. Gold has been obtained from placer deposits in Alaska, diamonds off the coast of Africa and ores of the metals titanium and zirconium in Australian waters.

Giant kelp

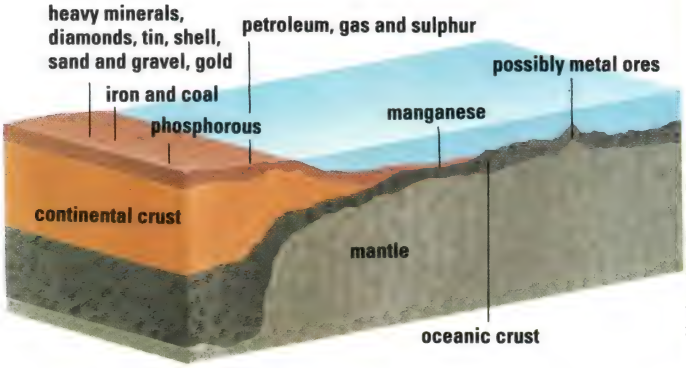
As knowlege of the structure and composition of the Earth's crust increases, geologists can predict the location of new sources of these and other minerals.

Ice-cream, toothpaste, plastics, paint, make-up and medicines are among the many products made using seaweed. An enormous type of seaweed called Pacific giant kelp is found off the west coast of America. Measuring up to 60 m in length, it can grow 45 cm in a day.

The kelp is harvested by back-

***Shallow water dredges** are dragged across the seabed by dredgers to recover minerals.* Posidonia Australis *(top), one of the few marine flowering plants, is used to make sacking.*

Nicholas Penn/Planet Earth Pictures



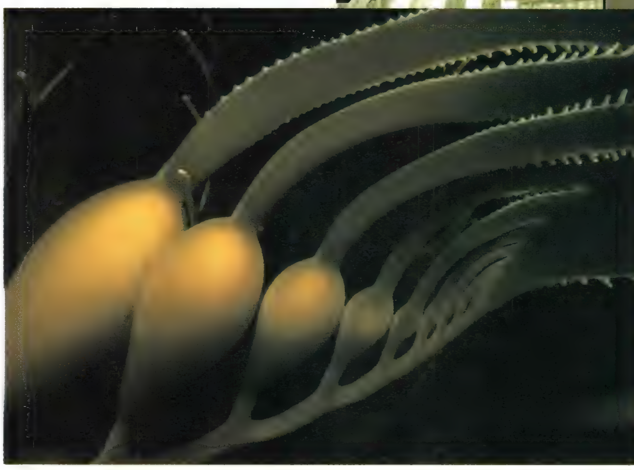
Mark Franklin

***Valuable mineral resources** on the seabed can be surveyed in shallow continental shelf waters by divers while at deeper levels, drilling and other techniques are used to locate the deposits.*

Norbert Wu/Planet Earth Pictures

***Seaweed** is now being used for a variety of high quality products such as a range of cosmetics, a type of dietary bread and a drink in which the plant is combined with sea water.*

Ivaldi/Jerrican



***Kelp bulbs** are not damaged by harvesting since the plant's long streamers are cut to just under a metre beneath the water. Cutting can even contribute to growth by allowing greater amounts of sunlight to reach the plants.*

ward-moving boats that slice the tops off the plants with sharp, revolving blades and then drag them aboard. Later, the kelp is boiled in large vats and the jelly-like extract from it is used in manufacturing. Whole plants can be turned directly into animal feed and fertilizer.

The Japanese consume great quantities of seaweed, much of which is cultivated on special nets in Japan's shallow Inland Sea. Another edible seaweed, a delicate, red variety, grows naturally around Japan's shores and is collected from small boats using long, hooked poles.

Oysters

Oysters, clams, and shrimp are among the animals farmed in the sea. One oyster produces millions of eggs, which soon hatch into free-swimming larvae. The larvae attach themselves to any hard surface, normally a rock, and then develop into small oysters known as spat.

Oyster farmers distribute old oyster shells or even roofing tiles around the spawning grounds. They then collect these when coated with spat and transfer them to the shallow waters of a bay or estuary that has been cleared of starfish and other animals that eat oysters. Supported on wooden racks or suspended from wires, the oysters grow until they are ready to be harvested.

Pearls

A certain type of oyster, not the edible kind, produces pearls. This happens when a speck of grit gets inside the oyster's shell and acts as an irritant. The oyster builds up layers of a hard, lustrous chemical around the grit to protect itself.

In certain parts of Asia, skilled divers can stay underwater for several minutes while they search for natural pearl oysters on the seabed. But many pearls now come from farms in which tiny pieces of shell are placed inside the oysters. After three years, the oysters are opened and the so-called 'cultured' pearls removed.

Bathroom sponges

Most bathroom sponges today are man-made. However, the expensive, oddly-shaped, yellow sponges that you occasionally see on sale are the soft skeletons of primitive animals that live on the seabed.

Sponges have been found at all depths, from the shallows of inland seas to the ocean floor 6,000 metres down. They obtain oxygen and food by circulating seawater through the numerous channels in their bodies.

Only a few varieties can be used as bathroom sponges. These are collected by divers working as deep as 30 metres without any special equipment. At first, the living sponges are greyish and slimy. To clean them, they are washed, stamped on, or beaten. Then the skeleton is trimmed with a knife ready to be sold.

Gamma/Frank Spooner Pictures

***A pearl is formed** when an irritant such as a grain of sand finds its way into the shell of an oyster. To isolate the source of irritation, the oyster deposits a secretion around it.*

Just amazing!

PEARLY KING

THE LARGEST PEARL EVERY FOUND, THE PEARL OF ALLAH, CAME FROM A GIANT CLAM IN THE PHILIPPINES. IT WEIGHED 6.4 KG AND MEASURED 24 CM LONG BY 14 CM ACROSS.

Paul Raymonde

Q GENERATORS Q ELECTRONS Q POWER STATIONS

ELECTRICITY

A discharge of electricity flashes from one metal object to another. Metal has the kind of molecular structure that makes it an ideal conductor, so that it naturally attracts any unchannelled electricity.

WITH THE FLICK OF A SWITCH, a light, a stereo, a microwave oven or a computer comes instantly to life. These devices, and thousands of others that we take for granted in the modern world, work off electricity. But what is electricity and where does it come from?

An electrical current is a flow of tiny particles called electrons. Electrons are one of the basic building blocks of atoms, and are negatively charged: this means that they repel each other. Normally, the electrons swarm in clouds around the atom's nucleus, or centre, made up of a cluster of positively charged protons and ... In some atoms, however,

...de/Science Photo Library

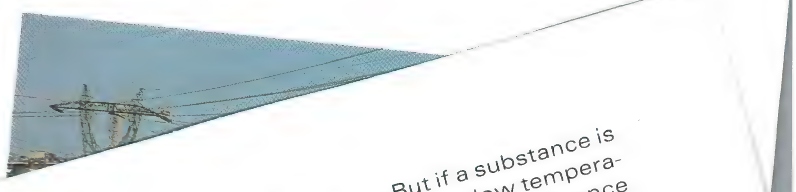
US Dept of Energy/SPL

Circuit breakers, like these ones at an electricity substation at Oregon City, USA, are a safety device. If lightning strikes an overhead cable, the circuit breakers switch off power to the rest of the cable to protect it.

some of the electrons are 'free' and orbit outside the atom. These free-electrons can travel in streams from one place to another, creating a current of electricity.

Substances such as metals, which contain many free or loosely held electrons, are known as conductors, since they allow electricity to pass through them very easily. Silver is one of the best conductors, but because it is so expensi

The control room *of a national grid system is the nerve centre of a country's electricity supply. Here, supply can be monitored, and the redirected t it is n*



National Grid Co

Tony Stone Photo Library London

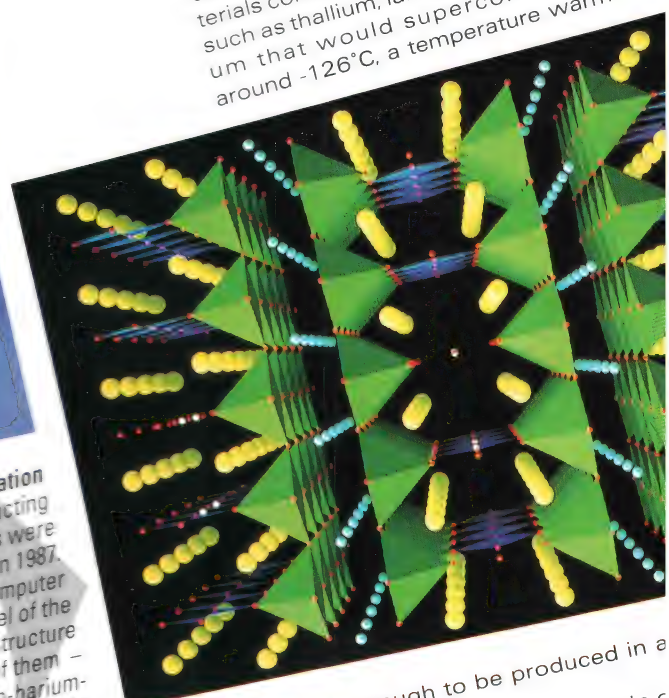
Superconductivity *is the wave of the future. Conductors at temperatures nearing –273° C – absolute zero – have almost no resistance to electricity. This means that a magnet can be held suspended in a loop of super-cold wire.*

wastes energy. But if a substance is cooled down to a very low temperature, it loses its electrical resistance altogether. It is then said to be 'superconducting'. With no resistance to slow it down, a current could theoretically flow around a superconducting circuit forever.

Warm superconductors

Until recently, the highest temperature at which a substance was known to superconduct was –250°C; the conductor was a metallic niobium-germanium alloy. But in 1986, there was a major breakthrough. Scientists discovered a number of complex materials containing metallic substances such as thallium, lanthanum and yttrium that would superconduct at around -126°C, a temperature warm enough to be produced in a laboratory.

These new materials c hope of practical applicatio perconductors in the future use might be in a national from superconducting power lines would not los gy during transmission. A of the new supercondu be in building an extremely fast computer.



Chemical Design Ltd/SPL

A new generation *of superconducting materials were discovered in 1987. This is a computer model of the molecular structure of one of them – yttrium-barium-copper oxide.*

used only tions in de The best lo virtually all w

Most oth plastics, cera paper, have ve and so prevent ing through th insulators. Hou

The filament in a ligh *made of very fine wire, keep bumping into the a the wire, making them vi and glow white with heat.*

as fo

so great that it affected the picture quality on many television sets!

All domestic electricity supplies are carried from the nearest substation by at least two wires, usually underground. These wires enter a fusebox where a number of fuses protect the circuits and appliances inside the house. A fuse is simply a wire that overheats and melts if too much electricity passes through it.

'Ring' main

Several circuits branch out from the fusebox. One type powers the ceiling and wall lights. Another is the main 'ring' circuit that runs around the house, between the walls and under the floorboards. Each circuit consists of a live wire and a neutral wire – which are both connected to the substation – and an earth wire that conducts current harmlessly to the ground if an appliance fails.

The amount of current entering the house is measured by a meter. This contains a small motor, connected to a counter, that runs faster as more electricity is consumed. The meter clocks up the amount of electricity used and the reading is then used to determine the amount of a household's electricity bill.

Even the best conductor offers some resistance to a current and so

Just amazing!

SHOCKING CURE

A SERIES OF RAPID, 25,000-VOLT SHOCKS, IT HAS BEEN FOUND, IS AN EXCELLENT CURE FOR THE BITE OF DEADLY SNAKES SUCH AS THE SOUTH ... MASTER

Power stations *transmit electricity at very high voltages, which is stepped down later for safe domestic use. High voltages cut transmission ... but huge*

Spectrum Colour Library

HI-TECH MINES   POWER STATIONS   POLLUTION

KING COAL

COAL SUPPLIES A HUGE SLICE of our energy needs, despite its reputation for being a dirty fuel and dangerous to extract. But the image of coal is changing. New technology is revolutionizing mines, while coal-burning is becoming cleaner and more efficient.

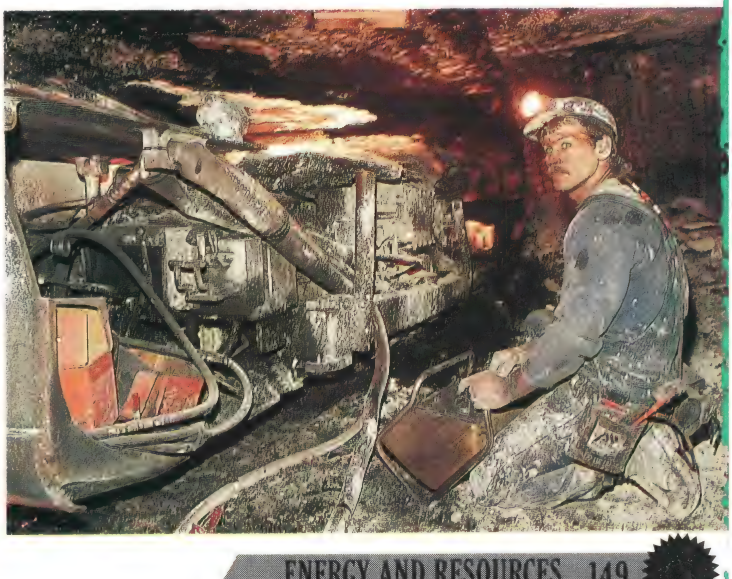
Most of the world's coal supplies started to form during the Carboniferous Period, from 360 to 280 million years ago. Decomposed plant matter in a moist environment, such as a swamp, broke down into peat. Buried underground, squeezed and heated, the peat gradually turned into coal, first into lignite, or brown coal, then (as the pressure and heat from above increased) into common bituminous coal, and finally into shiny black anthracite. A layer of peat around 5 metres thick will compress into a seam of coal some 30 cm deep.

As coal seams formed, the pressure forced out oxygen and hydrogen from the plant remains, leaving mainly carbon. Wood contains 50 per cent carbon, while lignite has 70 per cent and anthracite 94 per cent. It is the carbon that burns, helped by pockets of trapped oxygen and hydrogen gas.

Coal is mined by two distinct methods: surface mining and underground operations. In surface mining – also known as opencast or strip mining – the layers above the coal seams (the overburden) are stripped away. The overburden can be more than 100 metres deep. The biggest surface mines produce just under 50,000 tonnes of coal a day.

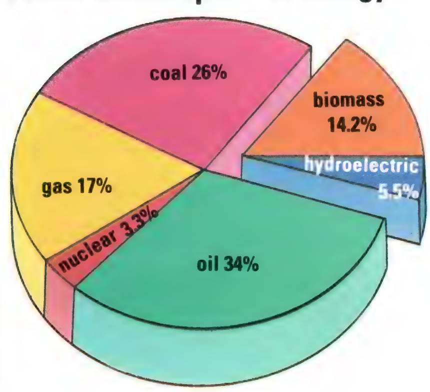
The majority of the world's coal, however, is brought up from underground, from seams as deep as 1,200

An opencast mine in Germany. The sides of a surface mine are cut away to form a series of steps called benches. So the deeper the hole, the wider the area it must cover. Much coal, however, is mined underground. This coal face (right), in a mine in Kentucky, USA, is sliced with vertical strokes by a series of cutting edges mounted on a drum.



Costain Group

World Consumption of Energy



Mark Franklin

***Coal, oil, gas and uranium** will all eventually become uneconomic to mine. The top two renewable sources are heat from burning organic matter (biomass) and hydroelectricity.*

Energie-Versorgung Schwaben AG

***Heilbronn power station,** run by operators manning computers in a central control room (below), is one of most modern coal-fired power stations in Germany, and one of the largest in the world to have a complete flue-gas cleaning programme.*

Energie-Versorgung Schwaben AG

metres below the surface. Geological surveys provide data on which are the most promising seams and how they are laid out. In the most up-to-date mines, cutting machines are steered from a computer console in an underground operations room.

As the excavation proceeds, electronic guiders on the cutter transmit signals back to the console giving the machine's exact position. Sensors around the mine also warn the control-room of that most feared danger – a potentially explosive build-up of methane gas. Other sensors monitor the quality of coal being extracted and tell if equipment needs replacing.

Electricity

The great majority of coal that comes out of the ground is consumed in power stations for making electricity. About 50 per cent of the UK's electrical energy, for example, is supplied by burning coal.

At a power plant, the coal is first pulverized into fine pieces so that it will burn more efficiently. The burning itself takes place in a huge, box-shaped boiler. The inner walls of the boiler contain tubes in which water is converted into steam. The steam passes through a superheater, where its temperature and pressure are increased, before it drives a high-pressure turbine. A shaft from the turbine turns a generator that produces electrical current. A typical boiler consumes 500 tonnes of finely ground coal an hour – enough to generate a million kilowatt-hours of electricity.

Reducing pollution

Burning coal creates a number of problems, however. It contributes to the global 'greenhouse effect' by producing large amounts of carbon dioxide. It also gives off a number of poisonous substances, the worst of which is sulphur dioxide. When sulphur dioxide mixes with water droplets in the air, acid rain forms. This has killed millions of trees across Europe and North America.

To reduce their environmental impact, coal-fired power stations are being equipped with a variety of pollution-control systems. The most important of these is a flue-gas-desulphurization system called a scrubber. An alkaline substance, usually lime or limestone, is mixed with water and sprayed on to waste gas coming up the flue. The sulphur dioxide combines with this slurry to form calcium sulphate, or gypsum. In another process, in which crushed coal and limestone are suspended in a blast of air while they are burning, the limestone captures 90 per cent of the polluting gases given off.

BURIED IN PEAT

Trustees of the British Museum

As vegetable matter is compressed beneath the living surface of a bog it gradually turns into thick, black peat. Dried and cut into bricks, peat was once used to insulate cottages and it is still burned as fuel in many parts of the world. It is also an amazingly good preservative of animal and human remains. In 1985, for instance, the skin-covered head and upper torso of a man (above) was dug up from a peat-bog near Wilmslow in Cheshire, UK. Analysis showed that he had been garotted – strangled with a twisted cord – around 2,000 years ago.

***Gypsum** is a by-product of the coal burning process at Heilbronn, produced when limestone slurry combines with the sulphur in waste gas. Pressed into briquettes, it is sold as a building material.*

Energie-Versorgung Schwaben AG

Just amazing!

THAT COAL BLACK MAGIC ...

AMONG SOME OF THE MORE SURPRISING PRODUCTS MADE USING COAL ARE NYLON, SACCHARINE SWEETENER, MOTHBALLS, WEEDKILLER AND ANTISEPTICS.

Paul Raymonde

BLACK GOLD GRAVITY SURVEYS HOT PONDS

HIDDEN RICHES

SOME OF THE DESERT areas of the world contain very rich mineral deposits. And in the Middle East, in particular, there are huge underground reservoirs of oil – a vital commodity for the economy of the world.

Four methods are used in finding sites to test drill for oil: surface feature mapping; seismographic observations; Earth gravity surveys and satellite sensing. The most obvious way is to look for signs on the surface such as tar sands or oil films on water in streams. A salt dome – bulging slightly in otherwise flat ground – is a good place to look as it is also a sign of an oil trap.

Satellite surveys

Remote sensing from satellites can speed up mapping and exploration. They show features that are invisible to the geologist in the field and cover vast areas. An important satellite for surveying is the Landsat Thematic Mapper. This takes pictures at wavelengths that are not normally visible. From these it is possible to tell apart common rock types and also detect potentially valuable formations. It shows up geological features, such as folds or faults. These features can ease the passage of fluids that concentrate metals and hydrocarbons.

Tony Stone Photo Library, London

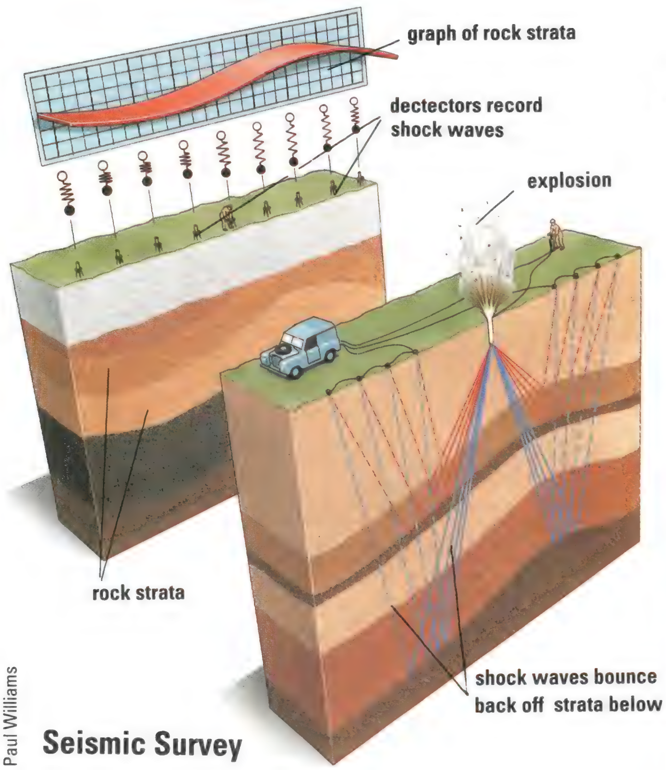
Pipelines (above) transport crude oil from wells to ports for shipping, or to refineries (below), which process petroleum into different oil products.

But as most subsurface folds and faults do not show themselves on the surface, geologists have to detect them by other methods. The first of these is likely to be the gravity survey. Although the acceleration due to gravity at the Earth's surface is relatively constant, it changes fractionally where there are heavier or lighter rocks close to the surface.

Sound waves

Salt domes can be picked out because salt is lighter than many other rocks and the gravity survey – usually carried out from the air – picks up a lessening of the gravitational field. Gravity surveys can also spot fault blocks and buried reefs, both likely sites for an oil accumulation.

When the gravity survey has shown up some likely spots, the geologist moves in to do more detailed seismic surveys. Different rocks transmit sound waves at different speeds and where two types of rock meet, sound waves are reflected. So by sending a



Paul Williams

To build up *a graphic picture of the subsurface, geologists record the shock waves generated by explosions and analyse their speed with computers.*

Mining for salt *in the Niger. Rock salt can be found even in land-locked countries, where the mineral was deposited millions of years ago by seas that have now evaporated.*


Dave Brinicombe/Hutchison Library

An open-cast *diamond mine in South Africa is being converted to deep mining. Although more expensive, underground mines are worthwhile for valuable minerals such as diamonds.*


De Beers Consolidated Mines Ltd

powerful vibration through rock, a picture of the features below can be built up, rather like a sonar or echo sounder at sea sees underwater features.

Finally, if the survey shows that there might be oil-bearing formations below, it is time to drill a test borehole. The familiar derrick with its rotating drill pipe tipped by the drill bit can bore as deep as 7,500 metres. Mud is pumped into the drill pipe hole to prevent unwanted fluids flowing into the hole and to carry rock samples and other fragments back to the surface.

If the reservoir is economically viable, a pipe slightly thinner than the borehole is sent down and cement is forced into the gap between the hole and this pipe. This seals the borehole from the oil so the casing has to be blown open by explosives, allowing the oil to enter the pipe. When the oil starts to flow or is pumped to the surface, the well is topped with a 'Christmas tree' valve to regulate the flow and allow apparatus to be lowered for repairs and assessment.

There are many other ores and minerals including gemstones extracted from desert or arid areas. These include the diamond mines of Namibia in southern Africa and those at Kimberley in Western Australia, estimated to contain one third of the world's natural diamond supplies; the town of Mount Isa in Australia where copper, lead, zinc and silver are mined; and the iron ore fields and mines at Zouerate in northern Mauritania in the Sahara.

There is plenty of sunshine in the deserts and there is also, usually, plenty of salt. These resources can be exploited separately and together. Sunlight can be converted into electrical current using semiconductor solar cells, focused by mirrors in a solar furnace and used to heat water or air in solar panels. It also has the power, combined with the dry air, to quickly evaporate water from a mineral-bearing mixture, leaving behind pure crystals. One example of this is the potash mine near Moab, Utah, USA.

Evaporation ponds

Water from the Colorado River is pumped down to the ore deposits over 900 metres below the surface. The ore dissolves in the water and the mix is brought back to the surface and stored in large, shallow evaporation ponds. After 12 months, pure potash crystals are left, for use in fertilizers, glass and soap.

One of most hellish mines on Earth was created by evaporation. In an area of north-eastern Ethiopia, called the Danakil Depression, the bed of Lake Assale is all that remains of a cut off and evaporated branch of the Red Sea. In temperatures regularly up to and over 50°C, miners lever huge slabs of salt from the lake bed, which are cut into bricks and taken by camel train to market.

Just amazing!

DOWN, DOWN, DOWN

THE BINGHAM CANYON COPPER MINE, UTAH, USA, IS SOME 800 METRES DEEP - THAT'S NEARLY TWICE THE HEIGHT OF THE WORLD'S TALLEST BUILDING.


Paul Raymonde

Interim Index (1)

This index is in alphabetical order. The six subject areas are keyed as follows: SF – SPACE FRONTIERS, NT – NEW TECHNOLOGY, F – FUTURES, PE – PLANET EARTH, ER – ENERGY AND RESOURCES, LW – LIVING WORLD. Complete articles are marked **bold**. So LW **77–80** is LIVING WORLD pages 77–80. File your index at the back of your binder for easy reference.

Interim Index (2)

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